THE

AMERICAN JOURNAL OF SCIENCE.

[THIRD SERIES.]

ART. IX.—*On hitherto unrecognized Wave-lengths;* by S. P. LANGLEY. (With Plates I to IV.)

WE have already* presented a description of the method by which we were able to fix the wave-lengths in the solar spectrum by direct measurement as far as about 23,000 of Ångström's scale. At this point the heat in the solar normal spectrum had become so feeble that it taxed the utmost limits of our capacity in 1881 to measure it; for it will be remembered that we are able to study the prismatic spectrum of the infra-red with comparative ease, because the prism condenses the heat; but the grating greatly diffuses and weakens it, so that, were it due to this cause alone, we should find measures in this part of the grating spectrum enormously more difficult than those in the prismatic. But independently of this, of the heat which belongs to any ray, our grating in general employs not over the tenth part. These causes combine to make the heat in certain portions, where we have been compelled to measure, almost infinitesimal.

We are led to take this labor, not primarily to settle the theoretical questions involved in determining the relation between dispersion and wave-length, (though these are most interesting), but with the object of providing a way which will hereafter enable any observer to determine the visible or invisible wave-lengths of any heat, whether from a celestial or terrestrial

* This Journal, vol. xxvii, March, 1884.

source, observed in any prism; and thus to gain that knowledge of the intimate constitution of radiant bodies which an acquaintance with the vibratory period of their molecules can usually alone afford us. It is this considerable end,—the opening up to research of the whole unexplored region of infra-red energy, not only from celestial but from terrestrial sources—which will, we trust, justify the labor devoted to the following determinations. It may be hoped that wider interest will attach to our task of demonstrating the character of a certain curve, when it is seen that a knowledge of its true form has ceased to be a matter of abstract speculation only, but will, in connection with what has already appeared, now introduce to us such large regions of research as we have just indicated. Over and above all this, however, we shall find our results also affecting opinion on the theoretical considerations regarding the relation of wave-length and dispersion just alluded to.

In previous communications I have given a representation of the solar heat spectrum terminating near $2^{\mu}\cdot7$ or $2^{\mu}\cdot8$ and I have stated that while there were feeble indications of solar heat below this point, yet that the solar radiation beyond seemed sensibly cut off, as though below this were a nearly unlimited cold band. I do not mean then, in saying that solar heat sensibly ceases below this point, to say that absolutely none can exist, but that none at any rate does exist sensible to the delicate apparatus with which these first determinations were made, and that none in any case exists of an order comparable with the smaller portions of that already described.

The reader will gather a more clear conception of the difficulty of decision and of the almost infinitesimal amount of this solar heat below 3^{μ}, if it exist, by looking at Plate I in connection with the statement, that if there be any solar heat at 4^{μ}, the highest ordinate representing it on the same scale as that shown on the left of the Plate, would at any rate not occupy the thickness of the horizontal line which represents the axis of abscissæ. However, since we are rather inclined to admit from our final experiments with our latest and most sensitive apparatus, that heat of some kind reappears here near 4^{μ}, whether from the atmosphere of the sun, or elsewhere, insensible to the thermopile, and in any case, if it be real, almost infinitesimal in degree, or of the same order of intensity with that in the lunar spectrum; our statement that no sensible solar heat exists here must be taken under this qualification.

New Apparatus.

The apparatus for the determination of wave-lengths in connection with the flint glass prism has been already described.*

* See this Journal, March, 1884.

The following is the same in principle, with certain changes to adapt it either to the solar or electric heat. Let S, be the first slit, (see Plate III). For solar heat it has doubly moving jaws, controlled by a micrometer screw, while in the case of the electric arc we use a special form of slit surrounded by water, to be directly described. G is the large concave grating. The massive beam A, already described, carries the large rock-salt train S_2, L_1, P, L_2, B. G is fixed at the extremity of the beam, so that its collimating axis coincides with that of L_1, and by means of an automatic apparatus, not shown here, the slits S_1 S_2 are caused to lie always in the same straight line at right angles to G S_1. Under these circumstances, it has been demonstrated by Professor Rowland that the wave-length of light, passing through the slit S_1 to fall upon the grating and there be diffracted to S_2, is directly proportional to the distance S_1 S_2. Accordingly, owing to this extremely simple relation, we are able to state at once what invisible ray or rays are at any moment passing through the slit into our rock-salt train. Our engraving represents the arrangement as fitted up for the heat of the electric arc, which is placed immediately in front of the special nozzle *n* carrying the slit S_1. We wish to employ the arc chiefly in the extreme infra-red beyond the solar heat, and where any heat is excessively minute. The hottest part of the electric arc is found in the pit or crater of the positive carbon, concealed from direct vision, and occupying a space of only 3 or 4^{mm} square, even in large arcs. The carbons then must be inclined in order that a horizontal beam may escape from this almost hidden crater, which owing to its small size, should be brought nearly in contact with the slit, in order to utilize the whole of its very minute area, while in this case the inclination of the carbons will prevent such approach. Experiments with various forms of incandescent strips and carbons, directed by clock-work in the ordinary position, have proved the necessity of adopting the special device by which we have finally overcome these difficulties. Figure 1, Plate III, shows in section and in front view, one-half full size, a special slit, conical in form, around which a current of water is forced to circulate. Figure 2 shows the carbons on a smaller scale and the apparatus which permits them to be set at any height, inclined at any angle to the vertical, drawn back or approached to any distance. They are usually placed almost in contact with the special slit S_1, and the need of the water circulation is obvious, were it only to prevent the sides of the jaws of the slit from melting, as they would otherwise soon do. There is however another necessity for this water circulation. The need of a slit which may be artificially cooled for measures in the extreme infra-red of the spectrum

from the electric arc, is rendered evident when we state that for these extreme wave-lengths, the arc radiation is comparatively so small, that *the heat from the hottest part of the dazzlingly bright carbon does not very greatly exceed that from a piece of melting ice.* If, then, we are to distinguish here between the radiation which passes through the open slit from the incandescent carbon and that which comes from the adjacent edges of the slit, which inevitably mingles more or less with the former, the difference between the two temperatures must be made as great as possible.

Following now on Plate III the course of the ray from this electric arc, we observe that it falls on the grating G (to be presently described), which spreads it out into not one but many superposed spectra, distributed along the circumference of a circle whose center is at O equidistant from G, S_1, and S_2. For clearer illustration, let us suppose ourselves about to measure the heat in some ray of the visible spectrum (such as that near D_2, whose wave-length is nearly $0^{\mu}{\cdot}6$) and that the line $S_1\,S_2$ is a scale of equal parts. In this case, the beam A will be moved so that while the grating remains at the intersection of N S and G A and normal to the latter, the slit S_2 will be brought close to S_1 in the position $0^{\mu}{\cdot}6$ on our scale of equal parts, whose zero is at S_1. Here, (if we suppose sunlight to be employed,) we shall see a brilliant spectrum filled with Fraunhofer lines crossing the front of the plate of the slit S_2. Beyond this the second, third and other higher orders of spectra are distributed on the circumference of the circle in which S_2 always lies. Were it our only object to discriminate the heat in this particular visible ray, we should not in this case need the slit S_2 or the prismatic train, but could place the bolometer directly at S_2. Since we make the ordinary use of the slit S_2 however, we suppose ourselves to be determining the prismatic dispersion, for a given wave-length, that is, it forms with the prismatic train an approximately homogeneous spectral image at B, which can be viewed, or measured with the bolometer, giving the value of n for a known value of λ. For the mere purpose of measuring the heat in the ray, or determining its wave-length here in the visible part, where there is but a single sensible heat-spectrum, we do not need slit S_2 at all, while the refractive index for a glass prism could be as easily determined as that for rock-salt. Besides this, we should find here a relatively abundant heat and could use so narrow a bolometer as to fix the position by it alone quite accurately. Very different, however, are all the conditions if we wish to measure, for example, a wave-length corresponding to 3^{μ} or 4^{μ} in the *invisible* spectrum and

in the new region which we are for the first time exploring. Glass is impermeable to this kind of heat, but with our rock-salt train and with the delicate apparatus previously described, there is little difficulty in discriminating it by the bolometer, where the prism alone is employed, and in mapping the deviation of each spectral ray as shown in Plate III of our paper in this Journal, Jan., 1886. But now that we wish to determine wave-lengths, the conditions are altogether different; for not only the grating enormously expands this part of the spectrum and has cut the heat down correspondingly, just where that heat is itself feeblest, (so that the heat in parts of this region, is something like $\frac{1}{1000}$ part of that in the corresponding prismatic spectrum), but instead of one visible, we have now to deal with numerous invisible, spectra, overlapping ecah other.

Here then the slit S_2 has an additional function to fulfill, namely, with the aid of the prism, to discriminate these invisible spectra from each other. Thus in the position actually shown in the drawing, which corresponds to a wave-length of $3^{\mu}\cdot5341$, i. e., of 35341· of Ångström, we should see the slit covered by a bright spectrum, due to several of the higher orders, while we know that the energy of the wave-length we are seeking is wholly invisible. If we place a pellet of sodium in our electric arc, we shall see the two sodium lines on the slit plate, of which D_2 will fall exactly on the slit, if it be in adjustment; but this sodium line evidently does not belong to the wave-length we are seeking.

There are in fact, passing through the same slit and lying superposed on one another by an unavoidable property of the grating, an infinite number of spectra in theory, of which in this case nearly twenty are actually recognizable, by photography, by the eye, or by the bolometer, and of which, to consider only those where the wave length is equal to or greater than that of the sodium line D_2* we have six spectra as follows:

a.	(visible)	6th	spectrum	D_2	$\lambda=0^{\mu}\cdot5890$
b.	"	5th	"	$\frac{6}{5}D_2$	0·7068
c.	(invisible)	4th	"	$\frac{6}{4}D_2$	0·8835
d.	"	3d	"	$\frac{6}{3}D_2$	1·1780
e.	"	2d	"	$\frac{6}{2}D_2$	1·7670
f.	"	1st	"	$6\,D_2$	3·5341

It is in this invisible underlying first spectrum, buried, so to speak, beneath five others, of which three are themselves invis-

* We have heretofore adopted Angström's notation in calling the more refrangible sodium line "D_1" We shall hereafter, however, in conformity with the now more general usage, call this line, whose wave-length in Angström is 5889, "D_2." The corrections to Angström are due to the researches of Messrs. Peirce and Rowland.

ible also, that lies the wave-length we are seeking; consequently, there are (to consider no others) at least six qualities of heat, of six distinct refrangibilities, whose wave-lengths are equal to or greater than that of D_2, which pass simultaneously through the slit S_2. They pass through the prism, and on looking through a telescope occupying the position of the bolometer tube, we shall by suitably directing the arm of the spectroscope see the light from the sixth one at *a*. Its wave-length will be $0^{\mu}{\cdot}5890$, corresponding to a measured deviation (in the case of the rock-salt prism, of an angle of 60° 00′ 00″ and a temperature of 20° C.) of 41° 05′ 40″. Now on replacing the telescope by the bolometer, the bolometer wire will feel this same ray which the eye has just recognized by its light, and, if the galvanometer be in a sensitive condition, the image will be thrown by the heat off the scale, while a little on either side of this position no indication will be given. The beam and the slit S_2 remaining in the same position, let us next suppose that the bolometer arm is carried toward *b*, in the direction of B. There will be no sensible deflection until it reaches the position *b* in the red, corresponding to a wave-length of $0^{\mu}{\cdot}7068$, and in the prism to an angle of 40° 33′ nearly, for there is no sensible heat except in the successive images of slit S_2 formed by the prism P in the line PB. Passing farther toward B we come into the heat in *c*, and next to the heat in *d* which is less than $\frac{1}{100}$ that in the direct prismatic image, when no grating is employed.

This was the utmost limit of our power of measurement in 1883, beyond this point radiations from the grating being then absolutely insensible, and the radiation at the point *d* itself being excessively minute, even in the solar spectrum, where the heat, so far as any is found, is as a rule far greater than that in the spectrum of the arc. Accordingly I have elsewhere observed that these measures could be carried on as well by a large electric arc as by the sun; but in fact, owing to the difficulties attendant on bringing the arc, which must be of immense heat, close to slit S_1, and to other causes, the sunlight would be preferable wherever it could be used.

Our observation of June 7, 1882, gave the value of the index of refraction corresponding to $\lambda = 2^{\mu}{\cdot}356$, which was the lowest possibly attainable by our then apparatus. Incessant practice and study, resulting in improvements already referred to, have enabled us finally to measure down to a wave-length of $9 \times \lambda D_2$ corresponding to a position much below *f*. We may add that in doing so, it is sometimes convenient to employ a bolometer wide enough to overlap the images in the other adjacent spectra of the higher orders, which we may usually do without con-

fusing them, owing to their feebleness compared with that of the first spectrum in which we are searching.

We usually, however, employ a bolometer of not more than 1^{mm} aperture, and this demands excessive delicacy in the heat-measuring apparatus, since the heat here is, approximately speaking, about $\frac{1}{10000}$ of that in the region between the sodium lines in the direct spectrum of a rock-salt prism. This is near the limit of our present measuring powers with the grating, even when every possible device is used to increase the extremely feeble heat in this part of the spectrum.

We commenced by using an electric arc with carbons 12^{mm} in diameter in the position indicated. These were supplied by an engine of three-horse power; but even in this case the pit of the crater did not nearly cover the very short slit (its length is 8^{mm}). For these last and most difficult measurements, we have been obliged to procure the use of an engine of twelve horse-power and carbons 25^{mm} (one inch) in diameter. With this enormous current the hottest part is not easily maintained in place. To keep it directly in front of the slit we have tried various plans, such as boring out the carbons lengthwise, so as to form hollow cylinders of them, and filling the core with a very pure carbon tempered to the requisite solidity. Ordinarily it will be sufficient however to first form the central crater by a drill. This gives us a persistent crater, whose light, in the position shown in the engraving, filled a slit whose vertical height is 8^{mm}. It is probably the intensest artificial heat ever subjected to analysis.

Bolometer.

The changes in the bolometer since it was first described (Proceedings American Academy, 1881) are superficial rather than radical, and refer chiefly to the form of the case, and facilities for its accurate pointing. The linear bolometer is now made to expose to the radiant heat a vertical tape or wire of platinum, iron or carbon. This is usually about 10^{mm} long and only from $\frac{1}{1000}$ to $\frac{1}{100}{}^{mm}$ thick, but according to its special purpose it is made from 1^{mm} to $0{\cdot}04^{mm}$ wide. In the latter case it appears like the vertical strand of an ordinary reticule in the focus of a positive eye-piece attached to the case and is movable by a micrometer screw. It is in fact in appearance a micrometer thread, controlled in the usual way, but which is connected with the galvanometer and endowed with the power of feeling the radiations, visible or invisible, from any object to which it is directed. For very feeble sources of heat, such as those with which we are here concerned, the strip is made as much as a millimeter in width, and is not provided with a micrometer screw, but moves with the arm carrying it,

and its positions are read by the divided circle of the spectrometer to 10″ (ten seconds of arc). It is this simple form of the instrument which has been used in the present investigation, and which is shown in Plate II. The bolometer is shown in position in the middle of the case where its central strip is accurately self-centered in the cylinder. For protection from air currents, since the obscure heat studied will be stopped by a glass cover, we must make use of the special device I have described, in the memoir just referred to, of successive chambers or drums separated by diaphragms with a common central aperture.

With these precautions, and with the special adjuncts before described, a bolometer with a strip $\frac{1}{25}^{mm}$ wide can be set by the invisible heat alone to within 10″ of arc, while in the ordinary use of the linear thermopile we are liable to errors of a considerable fraction of a degree. Even with a bolometer 1^{mm} wide, it will be subsequently seen, we can set to 1′ of arc. This refers only to the precision of pointing attainable; we will consider the sensitiveness of the instrument later in connection with the galvanometer.

Galvanometer.

It must be remembered that while the nominal sensitiveness of a galvanometer can be increased to any extent by increasing the astaticism of the needle (quite as nominal power can be multiplied to any extent on a telescope by altering lenses at the eye-piece), that the real or working capacity depends upon the ability to always obtain a like result under given conditions. Accordingly we have continued to devote great pains to extend our original conception, so as to make the galvanometer, as well as the bolometer, not merely an indicator of heat, but a real "meter," which shall distinctly answer the question "how much?" as to almost infinitely minute amounts of energy.

For the benefit of any physicists who may desire to repeat these experiments, we may observe that we have found the bolometer capable of almost unlimited delicacy of perception of heat, but that our chief trouble has arisen from the difficulty of constructing a galvanometer suitable to develop its full capacity for exact measurement. We have been unable to find among galvanometers ordinarily constructed one capable of indicating with precision changes in the amount of current of much less than $\frac{1}{1,000,000}$ of an Ampère. It was in the construction of a galvanometer designed to measure the heat in the spectrum of the moon, that we acquired the experience which we have utilized in the present researches.

A reflecting galvanometer of the form devised by Sir William Thomson has been used for the basis of our construction, and altered as follows. (For several of the changes described I am

indebted for suggestions due to the great kindness of Sir William Thomson and Professor Rowland.) First, the short suspending fiber supplied by the makers has been replaced by one 33^{cm} in length, stretched and prepared with particular care. Next, since the effect of a given minute change of current is proportionable (other things being equal) to the magnetic moment, and to the minuteness with which the angular deflection of the needle can be read, we have reconstructed the mirror and needles as follows. For the magnets* soft sheet steel $\frac{1}{20}$ of a mm. thick is rolled up into minute hollow cylinders each about 8^{mm} long and about 1^{mm} diameter. These are hardened and made to take a permanent charge of nearly 900 Gaussian units. Ten of these are placed behind the back of the mirror and ten below, making twenty in all. The reflecting mirror is accurately concave, being specially worked for the purpose, $9{\cdot}5^{mm}$ in diameter, 1 meter radius of curvature, weighing 63 milligrams and platinized on the front face by the discharge *in vacuo* of platinum electrodes, through the process of Professor Wright† of Yale College. The stem which unites the upper and lower system of the magnets is a hair-like and hollow tube of glass, while it occurred to me to replace the aluminum vane of the ordinary instruments, by the wings of a dragon fly (*Libellula*), in which nature offers a model of lightness and rigidity quite inimitable by art.

The glass plate which encloses the front of the galvanometer has optically plane and parallel sides, and the screen, placed at 1 meter distance from the mirror, is a portion of a cylinder 1 meter in radius, divided into 500 divisions of 1^{mm} each. The optical arrangements for illuminating and forming an image of the wire form one of such precision that a motion of $\frac{1}{10}$ of one of these divisions can be distinctly noted. There is an independent provision by means of which the image of a second opaque and inverted scale can be viewed by the observer through a telescope, not as in the ordinary construction, directed on to a flat, attached to the needles, but in which the concave mirror, already described, becomes itself the mirror of a Herschelian telescope. Ordinarily the condition of astaticism of the needle is such that without any damping magnet, it will execute a single vibration in not less than 15 nor more than 30 seconds. Much greater sensitiveness can be given to it, of course, but without, as we have found, corresponding advantage.

For the purpose of forming an estimate of the sensitiveness of the instrument, it may be stated that, when making a

* The design and construction of the hollow magnets is due to Mr. F. W. Very, of this Observatory.

† Professor Wright has had the goodness to platinize these delicate mirrors for us himself.

single vibration in 20 seconds a deflection of 1^{mm} division of the scale is given by a current of 0·000,000,000,5 Ampères through the coils of 20 ohms resistance; and, as we have just remarked, a tenth of one of these divisions can be discriminated. That this degree of sensitiveness is associated with a real, and not nominal, corresponding degree of accuracy, is shown by the fact that many series of accordant measurements have been made when the maximum deflection did not exceed three such divisions: and that similar measures have been made in the invisible spectrum given by ice melting in a dark room, when the maximum deflection observed was $1{\cdot}6^{mm}$ and most deflections less than one millimeter. On the other hand, the exposure of the same bolometer to ordinary direct sunlight with only $\frac{1}{1000}$ of the current passing, i. e. with the galvanometer shunted 1,000 times, would drive the needle immediately, and with violence, off the scale.

Our experience has shown us that this galvanometer, in conjunction with such a bolometer as we have described, is capable of recording a disturbance of rather less than $\frac{1}{10000000000}$ part. To attain corresponding accuracy in gravity determinations we should need to have a balance capable of weighing a kilogram which would give at the same time an unequivocal deflection for a difference of one one-thousandth of a milligram in either pan. A deflection of 1^{mm} corresponds, in the case of such a bolometer as we have used in the lunar spectrum, or in that of melting ice, to a change of temperature in the bolometer strips considerably less than $\frac{1}{100000}$ of a degree Centigrade, and we have just seen that about $\frac{1}{10}$ of this can be shown. In other words, about one-millionth of a degree can be indicated by it, and a quantity less than one hundred thousandth of a degree not only indicated but measured. It will be obvious to the practiced observer, that this degree of accuracy will not be in reality reached, unless the bolometer strips are perfectly protected from all extraneous radiations and air currents, and especially unless the image is fixed upon the scale when the bolometer is not exposed to heat. This degree of precision we believe ourselves to have actually obtained.

Gratings.

Of the concave gratings we have three, of the very largest size. These magnificent instruments we owe not only to the skill, but to the special kindness, of Professor Rowland, who has been good enough to execute them for us of the very short focus and open ruling, necessary for our particular work.

Let us designate them as gratings No. 1, No. 2 and No. 3. The dimensions of grating No. 1 have been given in a prior memoir, but we repeat them here with some other data, for the

reader's convenience. The limit of precision, imposed by the use of the bolometer, makes it superfluous to introduce any temperature correction, or to give the figures with more exactness than we here do.

NAME.	Grating No. 1	Grating No. 2	Grating No. 3
Radius of curvature	1626·mm	1753·mm	1627·mm
Number of lines to mm	142·1	142·1	113·7
Height of ruled portion	102·mm	80·mm	75·mm
Width of ruled portion	146·	132·	133·
Distance corresponding to 10,000 of Angström's units on the line of wave lengths, S_1S_2	231·0mm	249·1mm	185·0mm

The ruled portion of each of these truly superb instruments occupies from 100 to 150 square centimeters. On their exquisite definition we need not enlarge, since sufficient of them are now in the hands of physicists to make our commendation superfluous.

We have already described the action of the grating. The essential feature, for our purpose, is that, under the stated conditions, we can in theory be absolutely sure of the wave-length of the *invisible* ray under examination by choosing it a multiple of the wave length of some *visible* line in the superposed spectrum which is coincident with slit S_2.

Thus, in the case of our illustration, we have supposed the sodium line to be used, since this is conspicuous in that of the sun and easily reproduced in that of the arc. The wave-length we are in search of, is always a times the wave-length of D_2 (a being some aliquot number). In practice we thus, for greater certainty, always form the image of some line in the visible spectrum on slit S_2, although, as already explained, its mere position on the line $S_1 S_2$ is, if the apparatus be in adjustment, a guarantee that none but the exact ray and its multiple comes under examination.

Lenses and Prisms.

The rock-salt lenses, L_1, L_2, are of different focal lengths for different occasions. For the extremely feeble heat we are considering we are using very clear and perfectly figured salt lenses of 75mm aperture and 350mm focus; this small ratio of aperture to focus in the lenses being required to economize the feeble heat as much as possible. The prism used with them is first set to minimum deviation on some visible line, and then automatically kept there for the invisible ray under consideration.

We owe these specimens of rock-salt to the particular kindness of Professor Hastings of Yale College, and their extremely exact surfaces to Mr. Brashear of Allegheny, the maker of the

surfaces on which the Rowland gratings are ruled. On this portion of the apparatus alone very great labor has been expended.

We have procured through Mr. Brashear's skill, by means previously described, a rock-salt prism having a field filled with Fraunhofer lines and showing distinctly the nickel line between the D's. This is true when first polished, as it comes from the maker's hands; but owing to the deliquescent nature of the material, with the utmost care, the surfaces rapidly deteriorate. As it is necessary for the precision of these researches to determine the refracting angle of the prism, and also the indices of refraction of some of the principal lines in its visible and invisible spectrum with a high degree of accuracy, and as all these labors have to be repeated when the prism is re-polished, some idea of the work in this portion alone may be understood, when it is stated that the prism has been sent to the maker and entirely refigured, and its principal constants redetermined by us, no less than thirteen times in the past fourteen months, or since the first of January, 1885.*

We now give two examples of actual measurement of wave-lengths: the first, that in sunlight in a flint prism, which we have designated as No. 2; the second, in the rock-salt prism just mentioned.

First example of measurement. With flint glass prism.

(Extract from original record.)

Station, Allegheny.
Date, March 3d, 1886.
Temperature of apparatus $= -1°{\cdot}8$ Cent.
State of sky, clear overhead, cirrus clouds near the horizon.
Aperture of slit (S_1) $= 2^{mm}$.
Aperture of slit (S_2) $= 1^{mm}$.
Lenses of glass (non-achromatic) focal length $\doteq 800^{mm}$ for visible rays.
Grating, Rowland No. 1 (concave).
Prism, H. No. 2 (glass). Refracting angle $= 62°\ 15'\ 03''$.
Spectrum thrown east.
Galvanometer No. 3, damping magnet at 40^{cm}.
Time of single vibration $= 21$ sec. (with current passing).
Bolometer No. 16 (aperture $= 1^{mm}$).
Reading on slit (before mounting prism), $0°\ 00'\ 00''$.
Reading on D_2 (through prism), $52°\ 52'\ 40''$.
Current of battery $= 0{\cdot}036$ Ampères.†

* For a full description of the constants of this prism, see this Journal, Dec., 1885.

† It must be understood that this is the *total* current of the battery. The differential current which passes through the galvanometer is of an altogether different order of magnitude, in this case probably not exceeding 0·00000001 Ampère.

Reader at circle, F. W. V.
Reader at galvanometer, S. P. L.

OBJECT = measurement of deviation of $\lambda = 4 \times \lambda D_2$ in the spectrum of the flint glass prism H. No. 2 with sunlight.

Galvanometer deflection with arms in line (from the combined effect of all the grating spectra falling on slit 2) a little over 300 divisions.

Prismatic deviation.	49° 00′	48° 58′	48° 56′	48° 54′	48° 52′	48° 50′
Galvanometer deflections. First series	11 2	10 13	11 12	18 15	19 13	12 15
Mean deflections	6·5	11·5	11·5	16·5	16	13.5
Galvanometer deflections. Second series	13 14	21 22	26 24	32 31	25 30	20 13
Mean deflections	13·5	21·5	25	31·5	27·5	16·5

Concluded maximum at 48° 54′.

Making the galvanometer deflections ordinates, and the prismatic deviations abscissæ, a smooth curve through the points of observation gives, in the first case, a maximum of 48° 54′. The image of the slit has a certain size, and so has the bolometer strip. The latter feels the heat before the center of strip and image coincides, and it is this point of the coincidence of centers which gives the maximum as denoted by the above figures.

We now make a second series, and though the two series follow each other at a brief interval on a day described as "clear," the values of the deflections in the second series on the same points indicate nearly twice the heat in the first. The change is chiefly due to the altered diathermancy of the apparently clear sky in the brief interval. It is one of the difficulties already signalized by the writer and by others,* and is to be eliminated only by repeated observation. The second series, however, gives the same deviation as the first, and hence we conclude (as far as this day's observation goes) that this is the index of refraction for the wave-length in question and for a certain flint prism. Such observations must generally be repeated on many days before a reliable result is reached; and in the case of the glass prism, which grows rapidly athermanous just beyond the limit of the solar spectrum, they are limited, by the nature of the substance, to little more than the wave-length in question.

* See Crova, Comptes Rendus, vol. ci, p. 418, Aug. 10th, 1885.

We now consider as our second example a measurement at $5\times\lambda D_2$, where glass can hardly be used, and where its place is supplied with the rock-salt prism, and that of the sun by the arc.

Second example of measurement. With rock-salt prism.

(Extract from original record.)

Station, Allegheny.
Date, April 15th, 1886 (P. M.).
Wet bulb at $4^h\ 30^m$ (inside dark room artificially heated) = 21°·0 Cent.
Dry bulb at $4^h\ 30^m$ (inside dark room artificially heated) = 26°·4 Cent.
Aperture of slit $S_1 = 4^{mm}$.
Aperture of slit $S_2 = 1{\cdot}25$.
Prism used, Hastings No. 1 (rock-salt).
Lenses used, focus = 760^{mm} for visible rays.
Grating used, Rowland No. 2.
Galvanometer No. 3, damping magnet at 40^{cm}.
Time of single vibration = 17·5 sec. with current.
Bolometer No. 16 (aperture 1^{mm}).
Setting on slit = 0° 00′ 00″.
Setting on D_2 (spectrum thrown east) = 41°·03′ 00″.
Setting on D_2 (spectrum thrown west) = 319° 57′ 40″.
Current of battery = 0·037 Ampère.
Reader at circle, J. P.
Reader at galvanometer, F. W. V.
Arc managed by A.

OBJECT=determination with the great arc of the deviation in a rock-salt prism corresponding to a wave-length of $5\times\lambda D_2 = 2^{\mu}{\cdot}945$.

Spectrum thrown east.

Deviation.	39° 21′	39° 18′	39° 15′	39° 12′
First series	1·3, 1·3 → 1·3	3·3, 3·4 → 3·4	5·5, 5·4 → 5·5	2·3, 3·4 → 2·9
Second series	−1·0, −0·8 → −0·9	0·6, 1·6 → 1·1	7·5, 6·3 → 6·9	1·7, 1·7 → 1·7

Spectrum thrown west.

Third series	1·0, 0·4 → 0·7	2·1, 2·7 → 2·4	4·1, 3·9 → 4·0	0·2, −0·1 → 0·1
Fourth series	−0·1, 0·2 → 0·1	2·3, 2·4 → 2·4	3·4, 3·6 → 3·5	−0·1, 0·3 → 0·1

The sodium line of the fifth spectrum fell exactly upon the slit S_2 at the beginning and end of the observations.

From smooth curves the following positions were deduced for the maximum:

Spectrum east	39° 15′·7
Spectrum east	39 15 ·0
Spectrum west	39 16 ·0
Spectrum west	39 16 ·4
Mean =	39° 15′·8

The following measurements of wave-length with the grating have been carried on continuously from December, 1885, to April, 1886. As a rule each of the sixty-two determinations in the following table represents one or more day's labor, though in some cases two or more have been secured in the same day.

They have been taken under the following conditions:

(1.) In the case even of the very lowest wave-lengths in the feeblest heat, we have been able to use a linear bolometer of not more than 1^{mm} width.

(2.) About an equal number of observations were intended to have been taken with the prism placed so as to throw the spectrum east and west. In doing this a minute systematic error amounting at the greatest to less than 1′ of arc was found to be caused by flexure of the arm, due to the weight of the bolometer cable, and a correction for this has been applied. Otherwise the observations are given as originally made; and as the "probable error" here includes all the more or less systematic differences, due to the use of different gratings, and different positions of the apparatus, it may be considered to be in this case, a fair indication of the amount of error to be actually expected.

We do not know of any determination of the change produced in the refractive power of a rock-salt prism by varying temperature. A rough comparison of the deviations of Fraunhofer lines, incidentally measured in the progress of the work at different seasons, during which the temperature has varied nearly 30° Cent., together with the results of a single day's measures at temperatures differing by 17° Cent., have concurred in indicating a diminution in the deviations throughout the visible spectrum of about 11″ for a rise of temperature of 1° Cent.

We do not doubt that a temperature correction is also required for the invisible spectrum; but not having yet been able to satisfactorily determine any, we think it best to leave all the observations as they stand, uncorrected for temperature, and

offer them under this reserve, now, with the intention of returning to them hereafter.

In the following table we repeat for convenience, the results of certain optical measures made on September 14th, 1885, by Mr. J. E. Keeler with the rock-salt prism, whose refracting angle was on that date 59° 57′ 54″, and which we have reduced to 60° by the formula given in this Journal for December, 1885. The wave-lengths are those due to Peirce's and Rowland's corrections of Ångström, with which we have been favored by the authors before their formal publication.

In the succeeding portion of the table, we have the results of measures made with the bolometer in the invisible spectrum. The first column gives the source of heat; the second, the wave-length selected for measurement; the third, the grating employed; the fourth, the refracting angle of the prism on the day of observation; the fifth, the temperature of the apparatus; the sixth, the observed deviation; the seventh, the mean deviation corrected for flexure error and reduced to a refracting angle of 60°; the eighth the resulting index of refraction for rock-salt.

Source of Heat.	Wave Length.	Grating.	Refracting Angle.	Temperature.	Observed Deviation.	Mean Deviation Reduced to 60°.	Index of Refraction.
Sun	0μ·39687	------	59° 57′ 54″	24°	43° 14′ 44″	43° 17′ 15″	1·56833
	·48614	------	"	"	41 51 47	41 54 09	1·55323
	·51838	------	"	"	41 32 52	41 35 13	1·54975
	·58901	------	"	"	41 02 41	41 05 00	1·54418
	·58961	------	"	"	41 02 29	41 04 48	1·54414
	·65630	------	"	"	40 42 56	40 45 13	1·54051
	·75940	------	"	"	40 22 25	40 24 41	1·53670
Arc	$2\times\lambda D_2$= 1·1780	No. 1	59 57 20	24	39 46 0	---------	
	---- ----	------	"	"	46 40	---------	
	---- ----	------	59 58 50	26	48 20	39 49 18 ±12″	1·5301±·0001
Arc	$3\times\lambda D_2$= 1·7670	No. 1	59 57 20	24	39 31 0	---------	
	---- ----	------	"	"	32 0	---------	
	---- ----	------	59 58 50	26	32 30	39 34 06 ±12″	1·5272±·0001
Arc	$4\times\lambda D_2$= 2·3560	No. 1	59 58 50	26	39 24 0	---------	
"	---- ----	------	"	--------	22 40	---------	
"	---- ----	------	59 59 34	−1·1	22 24	---------	
Sun	---- ----	------	"	0·6	24 06	---------	
"	---- ----	------	"	0·6	25 06	39 24 18 ±18″	1·5254±·0001

Source of Heat.	Wave Length.	Grating.	Refracting Angle.	Temperature.	Observed Deviation.	Mean Deviation Reduced to 60°.	Index of Refraction.
Arc	$5\times\lambda D_2=$ 2·9451	No. 1	59° 58′ 20″	19°	39° 14′ 42″	.....	
	.....	.....	"	"	15 06	.....	
	.....	.....	59 57 45	21·8	16 48	.....	
	.....	.....	.....	"	16 30	.....	
	.....	.....	.....	"	15 18	.....	
	.....	.....	.....	"	17 42	.....	
	.....	.....	.....	"	17 24	.....	
	.....	.....	.....	"	15 36	.....	
	.....	.....	.....	"	16 00	.....	
	.....	.....	.....	23·8	16 18	.....	
	.....	.....	.....	"	15 54	.....	
	.....	.....	.....	"	15 48	.....	
	.....	No. 2	.....	26·4	16 30	.....	
	.....	.....	.....	"	15 48	.....	
	.....	.....	.....	"	15 12	.....	
	.....	.....	.....	"	15 36	39° 18′ 12″ ±2″·4	1·5243 ± ·0000
Arc	$6\times\lambda D_2=$ 3·5341	No. 1	59 58 20	14	39 04 00	.....	
	.....	.....	59 57 45	16	06 48	.....	
	.....	.....	.....	"	06 24	.....	
	.....	.....	.....	15	08 54	.....	
	.....	.....	.....	"	10 00	.....	
	.....	.....	.....	"	9 30	.....	
	.....	.....	.....	"	8 30	39 09 54 ±30″	1·5227 ± ·0002
Arc	$7\times\lambda D_2=$ 4·1231	No. 1	59 57 45	15	39 02 18	.....	
	.....	.....	.....	"	01 48	.....	
	.....	.....	.....	"	00 30	.....	
	.....	.....	.....	"	02 00	.....	
	.....	.....	.....	23·8	01 36	.....	
	.....	.....	.....	"	00 48	.....	
	.....	.....	.....	"	01 42	.....	
	.....	.....	.....	"	00 42	39 03 42 ±12″	1·5215 ± ·0001
Arc	$8\times\lambda D_2=$ 4·7121	No. 1	59 57 45	15	38 51 18	.....	
	.....	.....	.....	"	50 48	.....	
	.....	.....	.....	"	52 12	.....	
	.....	.....	.....	"	54 42	.....	
	.....	.....	.....	"	54 42	.....	
	.....	.....	.....	"	54 12	.....	
	.....	.....	.....	"	57 36	.....	
	.....	.....	.....	"	55 18	38 56 06 ±30″	1·5201 ± ·0002
Arc	$9\times\lambda D_2=$ 5·3011	No. 1	59 57 45	15·4	38 45 12	.....	
	.....	.....	.....	"	45 42	.....	
	.....	.....	.....	"	47 12	.....	
	.....	.....	.....	"	48 48	.....	
	.....	.....	.....	"	47 18	38 48 06 ±30″	1·5186 ± ·0002

In the following brief table we have summarized the results of all this labor. Our working method gave the index in terms of the wave-length, but since ordinarily the former is the known, and the latter the unknown quantity, we here give the mean probable error as finally corrected as a function of the latter.

Given Indices of Refraction in Rock-Salt Prism.	Wave-Lengths from Direct Observation, (*a*) by the eye. (*b*) by the bolometer.
1·5442	$\lambda D_2 = 0^{\mu}\cdot5890 \pm 0\cdot000$ (*a*)
1·5301	$2 \times \lambda D_2 = 1\cdot1780 \pm 0\cdot002$ (*b*)
1·5272	$3 \times \lambda D_2 = 1\cdot7670 \pm 0\cdot005$ "
1·5254	$4 \times \lambda D_2 = 2\cdot3560 \pm 0\cdot009$ "
1·5243	$5 \times \lambda D_2 = 2\cdot9451 \pm 0\cdot013$ "
1·5227	$6 \times \lambda D_2 = 3\cdot5341 \pm 0\cdot019$ "
1·5215	$7 \times \lambda D_2 = 4\cdot1231 \pm 0\cdot029$ "
1·5201	$8 \times \lambda D_2 = 4\cdot7121 \pm 0\cdot043$ "
1·5186	$9 \times \lambda D_2 = 5\cdot3011 \pm 0\cdot065$ "

In Plate IV, we have graphically constructed the relations between n and λ for the rock-salt prism, as far as the above wave-length of $5^{\mu}\cdot3011$ or $0\cdot0053^{mm}$. The ordinates are proportional to the indices of refraction given on the axis of Y, the abscissæ to the wave-lengths on the axis of X. The two vertical dotted lines carry the eye down to the corresponding portion of the spectrum, which is visible. Between these lines, lie the points of the visible spectrum observed on, and the dotted curves show the results of extrapolation by various formulæ.

The actual points settled by observation are certain multiples of the wave-length D_2 ($0\cdot0005890^{mm}$) and a small circle whose diameter equals a unit in the *third* decimal place of the scale of ordinates (indices) gives the position fixed by observation, while the distance from the center at which the smooth curve cuts the little circle furnishes a graphic presentation of its difference from observation. The labors of the past year, then, have enabled us to absolutely and directly measure the index of refraction of rays whose wave-lengths are greater than $0\cdot005^{mm}$, or more exactly, which reach 53011 of Ångström's scale, and to do so, with an error which is probably in most cases confined to the fourth decimal place of the index. As we shall see more clearly by Plate IV, the relation between n and λ has changed from that apparently complex one we see in the visible spectrum, so that n becomes almost a simple linear function of λ, and the results of extrapolation grow to a higher order of trustworthiness than when made from points in the visible spectrum alone.

It appears to us that no formula of dispersion with which we

are acquainted* gives entirely correct results on extrapolation, but that among the best are Briot's and Wüllner's. We have computed the wave-lengths corresponding to indices of refraction from observed deviations in the visible spectrum according to these formulæ. The curve from Cauchy's formula we do not give, because (at least when not more than three terms are taken from observations in the visible part of the spectrum), its results are here of little value, since it declares all the radiations we are now actually dealing with, to be impossible of discrimination at all. Redtenbacher's formula we have also shown in a previous memoir to be scarcely worth further consideration. The graphically constructed values are obtained by applying the formula of Briot,

$$\left(\frac{1}{n^2} = a + b\frac{n^2}{\lambda^2} + c\frac{n^4}{\lambda^4} + k\frac{\lambda^2}{n^2}\right) \text{.....to the four points:}$$

A ($\lambda = 0^{\mu}{\cdot}7601$. $n = 1{\cdot}53670$)
D_2 ($\lambda = 0^{\mu}{\cdot}5889$. $n = 1{\cdot}54418$)
b_1 ($\lambda = 0^{\mu}{\cdot}5183$. $n = 1{\cdot}54975$)
H_1 ($\lambda = 0^{\mu}{\cdot}3968$. $n = 1{\cdot}56833$)

and the formula of Wüllner, $\left(n^2 - 1 = -P\lambda^2 + Q\frac{\lambda^4}{\lambda^2 - \lambda_m^2}\right)$, to the three points:

A ($\lambda = 0^{\mu}{\cdot}7601$. $n = 1{\cdot}53670$)
b_1 ($\lambda = 0^{\mu}{\cdot}5183$. $n = 1{\cdot}54975$)
H_1 ($\lambda = 0^{\mu}{\cdot}3968$. $n = 1{\cdot}56833$)

All these are in the visible spectrum, and from them the constants a, b, c, k, P, etc., are determined. With their aid we next enquire, by the formula, what wave-lengths correspond to certain given indices, and the resultant values in the infra-red are then plotted from these computations. It is, however, only just to observe that the wide departure from observation here shown is by no means to be wholly attributed to error in the formula, for minute errors of measurement, such as are always present even in the observations in the visible spectrum, are immensely exaggerated by extending the curve through extrapolation. Wüllner's formula, for instance, would give a line closely coincident with our curve in the infra-red if we took all our points for computation from that part of the spectrum. A similar remark may be made of Briot's equation, whose actual tracing, however, with the constants we obtain from the visible spectrum, shows that beyond a certain point, the curve which is

* That proposed by Ketteler has come to the writer's knowledge too late for trial here.

its geometrical representation, from being concave to the axis of X, becomes convex, so that the relation between n and λ would, according to it, be represented by a sinuous line, and this is not so within the limits of these observations. Its fair agreement with observation then, within the limits of the visible spectrum and the upper part of the solar infra-red, are all that can be claimed for it.

Our conclusion is that all theories of dispersion known to us prove inadequate to predict the relation between wave-length and refraction.

The actual relation from direct investigation is here given for the first time from the observations of the past year, which it will be seen, thus confirm and greatly extend the results of 1882 and 1884. Their most salient feature is still perhaps that already noted, i. e. while the curvature, as far as we can follow it, grows less and less, at the last point at which we can view it the curve is not only all but sensibly a straight line, but one making a very definite angle with the axis of X. This obviously means that beyond this point n is nearly a linear function of λ or that the simple equation $n=a\lambda$ would very closely represent this portion of the curve. It means also that, as far as these observations extend, *we find scarcely any limit to the index of the ray which the prism can transmit* except from its own absorption.

I do not, it will be observed, undertake to advance without limit beyond observation, or to discuss what would happen with wave-lengths so great that the index became 0 or negative, as it would with an indefinite prolongation of the curve, if its direction remain unaltered. An intelligible physical meaning might perhaps be attached to these cases; but I here confine myself to the results of direct observation, and to the now established fact that the increase of the crowding together of the rays at the red end, which is so conspicuous a feature in the upper prismatic spectrum, has almost wholly ceased; and that the dispersion has become approximately uniform, the action of the prism here being assimilated to that of the diffraction grating itself.

I shall not venture to treat of the theoretical import of this, further than to remark that the ordinary interpretation of Cauchy's theory will apparently lead us to conclude that dispersion must sensibly cease at the point where the wave is so long that the size of the components of matter is negligible in comparison. In other theories also, there appears to be a point below which the index of refraction should never fall, and we might anticipate that the curve would accordingly tend to become parallel to the axis of X. Of course we cannot assert from observation that it will not finally do so, but

within the very extended limits in which we have followed it, the contrary happens, and the curve presents an increasingly constant angle with that axis.

These results, in some material points, are in contradiction to what has usually hitherto been believed.*

Let me repeat that one consequence of the fact that the curve is approaching a straight line is that, unless there is some immediate change in its character, such as we have no right to expect, extrapolation considerably beyond the point to which we have measured will be comparatively easy and safe. I am aware of the danger attending all extrapolations, but I must insist upon the fact that the old ones, which we have falsified by experiment, rested on extremely limited regions of the curve, that, namely, for the visible region of the spectrum, in which the relation between n and λ is also wholly different; while those, on which we now briefly enter, depend upon far greater material for induction (about eight times that included in the visible spectrum), which we can also use under much more favorable conditions.

Since the curve still presents a slight convexity to the axis of abscissæ, unless its character changes in a way which we have no ground to expect, a tangent at any point will meet that axis sooner than the curve itself will. Accordingly if we now ask what wave-length corresponds to any point in the hitherto unexplored region, for instance, the maximum in the spectrum of boiling water whose index† for the rock-salt prism is 1·5145‡ or that of melting ice whose index is 1·5048, we can answer as follows: First, this unknown wave-length is at any rate greater than $5^{\mu}\cdot3$ since to this point we have investigated by direct measurement; second, since the tangent to our curve even at the point 5^{μ} meets the line corresponding to the index of the maximum heat in boiling water at over 7^{μ} and a line corresponding to the maximum ordinate in the spectrum of melting ice at over 10^{μ}, and since the curve without some change in its essential character cannot meet these save at still greater wave-lengths, it follows that the wave-length of the maximum of the spectrum from boiling water is probably at least $\cdot0075^{mm}$, and that of the maximum in the spectrum from melting ice is over $0\cdot01^{mm}$. In an article in the Comptes

* I am very desirous that they should be verified by physicists, and I have therefore given particulars in some detail of my methods and apparatus here. I have requested the skillful artists (Mr. Wm. Grunow, mechanician to the U. S. Military Academy, West Point, N. Y., Mr. J. A. Brashear, Allegheny, Penn.) who have so successfully constructed this apparatus, to place at the command of physicists all or any details of it.

† Determined as described in this Journal for January, 1886, by means of the apparatus shown in Plate II.

‡ See Plate III, this Journal for Jan., 1886.

Rendus of the Institute of France, January 18, 1886, and in preliminary memoirs, we deferred giving the actual values, but gave (explicitly as minimum values which we believed much within the truth) 5^{μ} to 6^{μ}. That our caution led us to understate the even then most probable value, may be seen from the statements just made, which are founded on still later observations.

As we proceed farther out, extrapolation becomes, of course more untrustworthy. We can only say that if the curve maintains its present inclination to the axis of X, the wave-lengths of the extreme radiations recognized in the rock-salt prism must indefinitely exceed $0{\cdot}03^{mm}$.

We have shown that the various complex formulæ founded on theoretical considerations differ from observation; and as we have remarked, they have the minor objection also of being extremely difficult of application to practical uses, owing to the inordinately tedious numerical computations involved where many places are to be calculated.

Struck by the resemblance of the actual curve of observation as viewed in a large graphical construction, to a hyperbola, I was therefore led some years ago to use the equation of the hyperbola as an empirical one for interpolations in the infra-red without attaching any physical meaning to it. The further the investigation has been pushed in that part of the spectrum, the more exact the resemblance has become. That it is noticeable, will be seen on consulting Plate IV,* where the hyperbola does not appear as a distinct curve, because its variation from the smooth curve of observation cannot be recognized on this scale.

In obtaining this we have proceeded as follows: Having five disposable constants, we have taken five nearly equidistant points on the smooth curve of observation, remembering that if the axis of Y is not exactly asymptotic to the curve thus described, we are not necessarily to impute the difference to the equation chosen, since the condition that the curve of observation shall be rigorously asymptotic to this axis can in any case only be satisfied by infinite exactness of measurement.

It will be observed that my estimates of the extreme wave-lengths are in no way founded on the use of this hyperbola, and that I do not assert that it has any physical meaning.

I have elsewhere observed that while Herschel in 1840, Draper in 1842, Fizeau and Foucault in 1846, Lamansky in 1870, together with others since, had observed bands in the infra-red prior to 1881, yet that nothing was exactly known as to the

* It should be mentioned that some of the observations on which the computations are founded have been added since this drawing was prepared for the engraver.

wave-lengths of these bands, even to those who discovered them. It is very likely that the (probably telluric) absorption band in the solar spectrum placed on the Allegheny chart (Comptes Rendus, Sept. 11, 1882) at $1^{\mu}{\cdot}38$ had been recognized by more than one of the above mentioned observers, yet so little was known as to its actual position, even a few years since, that we find the elder Draper, in reviewing these former observations in 1881, and speaking with the authority of one who was himself a discoverer, expresses his doubt as to the possibility of any wave-length so great as $1^{\mu}{\cdot}08$ having really been observed, and M. H. Becquerel (Annales de Chimie et de Physique, 1883, tome xxx, p. 33) gives the wave-length of the longest band known to him as $1^{\mu}{\cdot}50$. These remarks will not be superfluous as an introduction to the following table, which presents a summary view of the advances made beyond the above-named point in the last five years.

Extreme lengths of visible and invisible etherial radiations and of sonorous waves.

Quality of radiation and means of recognition.	Wave-lengths in units of one millimeter.	Description.
Invisible ultra-violet radiations.	0·000185	Extreme rays of aluminum in the induction spark. Recorded by photography.
(Photography.)	0·000295	Extreme limit of solar spectrum at sea-level on best days, according to Cornu, recorded by photography.
Visible radiations.	0·00036	Limit of lavender light, visible to normal eyes.
(Eye.)	0·00081	Extreme limit of deep red light, visible to normal eyes.
Beginni'g of infra-red (Phosphorescence.)	0·0010	Supposed extreme possible limit of infra-red wave-lengths in 1881, according to J. W. Draper.
Photography, (Abney). Phosphorescence, (Becquerel).	0·0015	Wave-lengths assigned by H. Becquerel to lowest absorption band known to him in 1883.
(Bolometer.)	0·0027	Sensible limit of solar infra-red rays which penetrate our earth's atmosphere. Determined by the grating and bolometer, Allegheny, 1882.

Quality of radiation and means of recognition.	Wave-lengths in units of one millimeter.	Description.
Invisible infra-red radiations from terrestrial sources. (Bolometer).	0·0053	Limit of absolute measurement of wave lengths corresponding to a given index of refraction in the case of a rock-salt prism. Determined by the Rowland grating and bolometer, Allegheny, 1886.
	0·0075	Approximate position of the maximum ordinate in the heat spectrum from a lamp-blacked surface at the temperature of boiling water (100.°). Allegheny, 1886.
	0·011	Approximate position of the maximum ordinate in the "heat" spectrum from a lamp-blacked surface at the temperature of melting ice (0°). Allegheny, 1886.
	0·030	Approximate estimate of the minimum value assignable to the longest wave recognizable by the bolometer in any heat from a rock-salt prism.
Sonorous Vibrations. (Ear.)	14·0	Length of shortest sound wave corresponding to highest musical note perceptible by human ear. (Approximately 48,000 s. v. per sec.) Savart.

Broadly speaking, we have learned through the present measures with certainty of wave-lengths greater than $0{\cdot}005^{mm}$, and have grounds for estimating that we have recognized radiations whose wave-length exceeds $0{\cdot}03^{mm}$, so that while we have directly measured to nearly 8 times the wave-length known to Newton, we have probable indication of wave-lengths far greater, and the gulf between the shortest vibration of sound, and the longest known vibration of the ether, is now in some measure bridged over.

In closing this memoir, I must add that the very considerable special expenses, which have been needed to carry on such a research, have been met by the generosity of a citizen of Pittsburgh, who in this case, as in others, has been content to promote a useful end, and declines publicity for his name.

I cannot too gratefully acknowledge my constant obligation to the aid of Mr. F. W. Very and Mr. J. A. Keeler, of this Observatory, who have labored with me throughout this long work. In the prolonged numerical and other computations rendered necessary, I have been aided by Professor Hodgkins, of Washngton, and by Mr. James Page of this Observatory.

Allegheny Observatory, May 31, 1886.

ART. X.—*On the chemical composition of Herderite and Beryl, with note on the precipitation of aluminum and separation of beryllium and aluminum;* by S. L. PENFIELD and D. N. HARPER.

1. *Composition of Herderite.*

THE rare material for carrying on the present investigation of herderite was given to us by Mr. L. Stadtmüller and Professor George J. Brush. The crystals were carefully picked by hand and freed as far as possible from all foreign matter. They were then crushed and sifted and suspended in the Thoulet solution; only the material whose specific gravity was greater than 2·95 was used for analysis. By this means there was separated from the hand-picked crystals a little questionable material, which was used in making a sort of preliminary analysis, and we were able to obtain over five grams of very pure material. Before making the separation with the Thoulet solution we carefully took the specific gravity of some of the purest crystals by taking the specific gravity of the solution in which they were suspended without floating or sinking. This we found to be from 3·012 to 3·006, the heaviest being the specific gravity of a very clear transparent crystal, while the more opaque and cracked crystals were a trifle lighter. The mineral is so much heavier than the quartz and feldspar to which the crystals were attached, that we feel very confident of the purity of the material which we analyzed.

The analysis was made after we had had considerable experience in the determination of beryllium and had made some experiments in determining it in presence of phosphoric acid. The method which we adopted gave good satisfaction, and we give it here somewhat in detail. The mineral was dissolved in nitric acid, the solution concentrated to a small volume, sulphuric acid was added, and the gypsum crystals after being collected by filtering through a rubber funnel were ignited and weighed as $CaSO_4$. The filtrate was concentrated in a platinum dish and gently ignited to drive off all hydrofluoric acid and the excess of sulphuric acid. The residue was dissolved in hydrochloric acid, a basic acetate precipitation of a part of the beryllium and phosphoric acid was made in the cold with ammonium acetate, and a little calcium precipitated from the acetic acid filtrate by ammonium oxalate, which was ignited and weighed as CaO. The beryllium in the filtrate from calcium oxalate was precipitated as a phosphate by means of ammonia, filtered, and the phosphoric acid in the filtrate precipitated with magnesia mixture. The two precipitates containing the beryllium as phosphate (the basic acetate pre-

cipitate contained the bulk of the beryllium) were ignited in the same crucible and fused with sodium carbonate. The fused material was soaked out in water, phosphoric acid obtained in the solution by the usual method, while the insoluble beryllium oxide was dissolved in hydrochloric acid, precipitated with ammonia, weighed, and the trace of P_2O_5 contained in it separated with ammonium molybdate. The P_2O_5 and bases in analysis III, on which we place the greatest confidence, were separated and determined in the above manner.

Other determinations are given to show the accuracy of the method. The CaO in II was all obtained in the filtrate from the basic acetate precipitation and was not partially precipitated as gypsum. The BeO in the same analysis was tested for Al_2O_3, but not more than a questionable trace could be detected. The P_2O_5 in I was from a direct determination with ammonium molybdate, but a very slight mechanical loss was incurred. The fluorine was determined in III by driving off the silicon fluoride and titrating the hydrofluosilicic acid by means of a standard alkali.* After making the determinations, fresh U-tubes were connected with the apparatus and the aspiration carried on for several hours, but no more silicon fluoride was driven off. As our alkali had just been standardized by means of sodium carbonate and test experiments on fluor spar, we feel very confident that the fluorine determination is correct. The water determinations are somewhat surprising. Mackintosh† made no tests for water, and considered the mineral to be an anhydrous phosphate with fluorine. Winkler‡ made no determination of fluorine and obtained no satisfactory tests for that element by etching glass. He obtained a loss by ignition, however, of 6·59 per cent in the Stoneham mineral by strong ignition, which he regards as water. Genth§ obtained 6·04 per cent of fluorine by direct determination, and 0·61 per cent of water by heating the mineral with lead oxide to bright redness. Mackintosh‖ obtained good tests for fluorine by etching and found a loss of 6·03 per cent by strong ignition. He proved conclusively that fluorine was given off by strong ignition, and concludes that it is replaced in part at least by oxygen. We are scarcely willing to believe that such a reaction would take place on heating an anhydrous phosphate containing fluorine. Our first water determination was made by weighing out the mineral in a boat, placing it in a combustion tube containing a layer of dry sodium carbonate, igniting the tube to full redness and collecting the water in a weighed chloride of calcium tube. We obtained 0·69 per cent; afterward the mineral was dissolved, and analysis II completed

* Am. Chem. Journal, i, 27. † This Journal, III, xxvii, 135.
‡ Neues Jahrbuch für Mineralogie, 1884, ii, 134.
§ Proc. Amer. Phil. Society, xxi, 1884, 694. ‖ This Journal, III, xxviii, 401.

from the same material. After almost completing our analysis and finding only 5·27 per cent of fluorine we tried the following experiments. A little herderite powder was placed in a hard glass tube, sealed at one end and ignited; at first only a slight film of water condensed in the cold part of the tube; by strong ignition over the blast lamp, however, there was a sudden evolution of hydrofluoric acid, which etched the glass very perceptibly near the mineral and deposited a film of silica and very acid water, as marked as in an ordinary reaction for fluorine in a closed tube with acid sulphate of potash. In our experience we have never seen any hydrous fluoride which gives off such strongly acid water and such a marked fluorine reaction. Some of the powdered mineral was placed in a closed glass tube, covered with a layer of dry sodium carbonate and strongly ignited; neutral water was given off and condensed as a ring, which indicated more than a trace of water. The water was obtained in the following way. About two grams of calcite were ignited over the blast lamp till a constant weight was obtained. The mineral was then weighed into the same crucible, the lime was slaked with water, the contents of the crucible were carefully dried and then ignited till constant weight was obtained, the water being calculated from the loss of weight. The slaking of the lime makes an intimate mixture of the mineral with the lime, and a preliminary experiment proved to us that only neutral water was driven off. In I there was a slight mechanical loss in slaking the lime, which caused the water determination to be too high, the P_2O_5 too low. In III the water was obtained from a larger quantity of mineral. No sublimate was formed on the cover of the crucible by the volatilization of any fluoride. The analyses were made on air-dry powder which lost 0·10 per cent by drying for one hour at 100° C. The beryllium precipitates were always of a light cream color after ignition, indicating that not more than a minute trace of iron was present.

The following quantities of mineral were used in making the analyses: I. ·4552 grams; II. 1·0029; III. P_2O_5 and bases ·7336, F ·9692, H_2O 1·1612.

	I.	II.	III.	Ratio.		Calculated.
P_2O_5	43·47	- --	43·74	·308	1·	43·83
BeO	----	15·28	15·51	·620	2·01	15·44
CaO	----	33·61	33·67	·601	1·95	34·57
F	----	----	5·27÷38	·138 } ·343	1·11	5·86
H_2O	4·37 ?	----	3·70	·205 }		2·77
			101·89			102·47
O equivalent of F.....			2.22			2·47
			99·67			100·00

The ratio of $P_2O_5 : BeO : CaO : (F_2+H_2O) = 1 : 2 : 2 : 1$ nearly. The high temperature at which the water is driven off indicates that it is not water of crystallization, but is very firmly united in the mineral as hydroxyl, every H_2O representing two hydroxyl groups, and the OH being probably isomorphous with F. The ratio of F : OH is nearly 1 : 1, or more nearly 3 : 4 in our analysis. In the calculated analysis we have used the ratio F : OH = 1 : 1, but recognize that it is probably simply a case of isomorphism. The composition of herderite is, therefore, an isomorphous mixture of $CaBeFPO_4$ with $CaBe(OH)PO_4$, which may be written $CaBe(FOH)PO_4$, or a salt of phosphoric acid, two of whose hydrogen atoms have been replaced by a bivalent element, and the third likewise by a bivalent element whose other free affinity has been satisfied by a fluorine atom or hydroxyl. This is the same composition as that proposed by Mackintosh, except that he regarded the mineral as simply the fluorine compound and did not detect the water. Chemically herderite is closely related to the three minerals—wagnerite, triplite and triploidite, whose compositions are respectively Mg_2FPO_4, $(FeMn)_2FPO_4$ and $(FeMn)_2(OH)PO_4$. These three minerals offer the best illustration we have of the isomorphism of F and OH, and we feel that we have in herderite another strong proof of the correctness of this interesting relation. In crystallization the minerals vary, herderite being orthorhombic, triplite questionable, and wagnerite and triploidite monoclinic. The latter two have, like herderite, a prismatic angle of nearly 120°.

2. *Analysis of beryl.*

In 1884 one of us* published a series of analyses which showed that alkalies are present in beryl sometimes to quite a large extent, and that water is always given off by ignition. At the time the analyses were made the author had had little experience in the determination and separation of beryllium and used the ammonium carbonate method, which seemed to him to be the most accurate. Our experience has taught us that the method used in the manner described in the above mentioned article gives too low results for beryllium, and the analyses are only of value as showing to what extent alkalies and water are present in beryl. Since the publication of the article it has always been the author's wish to make a series of experiments on the separation of aluminum and beryllium and renew the investigation.

We have considered it best not to make a long series of

* S. L. Penfield. This Journal, III, xxviii, 25.

beryl analyses, but to select some very pure beryl and make an analysis of it as carefully as possible. The analysis was made according to the method described at the end of this article, and we feel assured from our experience that the results of the analysis represent the composition of the mineral very closely. The beryl which we selected for analysis was a very pure transparent aqua marine from Stoneham, Maine, furnished to us by Mr. George F. Kunz of New York. The mineral was crushed and ground in a steel mortar and the fine powder boiled in dilute hydrochloric acid, washed and dried at 100° C. Duplicate analyses were made by both of us, so that we might obtain a very fair average.

Specific gravity taken on a chemical balance, 2·706.

		Ratio.		
SiO_2	65·54	1·092		6·
Al_2O_3	17·75	·172	·173	0·95
Fe_2O_3	·21	·001		
FeO	·38	·005		
BeO	13·73	·541	·558	3·06
CaO	·06	·001		
Na_2O	·71	·011		
Li_2O	trace			
H_2O	2·01	·112		0·61
	100·39			

The ratio of $SiO_2 : Al_2O_3 : RO : H_2O = 6 : 1 : 3 : ·5$ nearly. The ratio of the first three is in the proportion required by the usually accepted formula for beryl. This conclusion was also arrived at by Baker* in a recent analysis made according to the same method which we used. As regards the alkalies, we have as yet no proof that they replace the beryllium, but that is probably the case. Analyses of beryls very rich in alkalies would best settle this question. The water is very constant, about two per cent, in all beryls which have come to our notice, with one exception—Aduntschilon, Siberia†—and must be in some way very firmly united in the molecule, as it is only given off by very strong ignition. As can be seen by our ratio, there is about one-half a molecule present. Beryls which show a higher percentage of water may, and in some cases which have come under our observation do, contain mechanical inclusions of water. Regarding the water as essential, we would have to add $\frac{1}{2}H_2O$ to the ordinary accepted formula of beryl, or write it $H_2Be_6Al_4Si_{12}O_{37}$. The theoretical composition according to the above formula is

* American Chem. Journal, vii, 175. † This Journal, III, xxviii, 29.

SiO_2	65·81
Al_2O_3	18·83
BeO	13·71
H_2O	1·65
	100.00

We can add also the alkali determinations in the following European beryls. The alkalies were determined by Smith's fusion method and calculated as sodium, although they all contained some lithia. Limoges, France, 0·73 per cent; Hühnerkobel near Bodenmais, Bavaria, 1·20 per cent; Habachthal, Tyrol, 2·26 per cent.

3. *On the precipitation and washing of aluminum.*

Before making the above investigations we tried a few experiments in the precipitation and handling of aluminum precipitates which may be of interest to some of our readers. A standard solution of aluminum chloride was first made containing ·1002 grams Al_2O_3 and 1 c.c. pure concentrated HCl in every 50 c.c. which were used in our experiments. The precipitation of the alumina was in all cases made in a volume of about 300 c.c. by neutralizing the solution with ammonia till the odor of ammonia could be distinctly obtained from the hot solution; the beaker was then placed upon a lamp stand and the solution brought to boiling, which was not continued more than one minute. The precipitates were in all cases washed without a pump, but suction tubes 7 inches long were attached to the funnels which cause a gentle suction, and if the filter papers are carefully fitted to the funnels very materially hasten the filtration.

The following facts were observed: that precipitates which were made in solutions containing large quantities of acid, either hydrochloric or nitric, filtered as well or better than those from solutions containing little ammonia salts, but on washing with boiling water the precipitates from solutions containing large quantities of ammonia salts became very sticky, washed slowly, so that it was almost impossible to free them from the last traces of ammonium chloride, and that very perceptible quantities of alumina settled out from the filtrates and washings on adding a few drops of ammonia and allowing the beaker to stand in a warm place. Further, that all of the alumina which ran through did so during the washing. The precipitates after they had become slimy and sticky seemed either to be quite soluble in the hot water or else got into such a condition that they readily passed through the pores of the

paper and stopped them up, thus hindering the filtration. To make a successful precipitation and washing of alumina it is quite essential not to have very much ammonia salts present and even with the greatest care it is found that if the filtrates and washings are set away in a warm place, slight precipitates will almost invariably settle out. The above holds good for solutions containing ammonium chloride and nitrate. The fact that alumina passed through the filter only during the washing suggested to us that if we could wash the precipitate with a saline solution which would be completely volatile and do no harm to the precipitate we might avoid the passage of the alumina through the filter and it might also hinder the packing of the precipitate. Ammonium nitrate suggested itself to us as a salt which would be volatile on ignition and do no harm, and our experiments with it have been very satisfactory. The following strength of NH_4NO_3 has been used in all of our experiments—2 c.c. of pure concentrated HNO_3 neutralized with ammonia and diluted to 100 c.c. with water; this strength has proved so satisfactory that we have tried no other. Using this hot saline wash instead of hot water the precipitation can be made in solutions containing large or small quantities of ammonium salts and no very great care is needed in adding the ammonia. According to our experience, the precipitates from solutions containing a goodly quantity of ammonia salts, resulting we will say from 4 to 8 c.c. of pure concentrated hydrochloric or nitric acid, filter and wash better than precipitates from solutions containing less saline matter. After having made a large number of precipitations we can say that only in one or two cases have we found a trace of alumina in either the filtrate or washings, and that unless the precipitate becomes too dry and packs too firmly upon the sides of the funnel, the washing goes on as well at the end as at the beginning, and there is no difficulty in washing the precipitate free from all traces of chlorine.

Where large quantities of sodium or other fixed salts are to be removed and a second precipitation of the alumina is required, we recommend that the first precipitate after washing be dissolved in nitric instead of hydrochloric acid, then very little washing is enough to free the second precipitate from the last traces of chlorine and fixed salts.

Why ammonium nitrate acts in this way we are not able to state. It may be something on the same principle that sediment deposits much faster in saline than in fresh water. We are convinced that any one who has to handle troublesome alumina precipitates will find the above method of washing of great advantage.

4. *On the separation of aluminum and beryllium.*

Various experiments convinced us that the following methods are not satisfactory: pPrecipitation of the alumina as basic acetate, some beryllium being also precipitated; precipitation of the alumina with barium carbonate; solution of the beryllium in a boiling solution of ammonium chloride; by long boiling of a solution of ammonium chloride the solution becomes slightly acid and according to our own experience some alumina is dissolved, while Genth* found that the beryllium was not completely dissolved. Solution of the beryllium in and precipitation of the alumina with ammonium carbonate gives unreliable results, and the method, when carried out as described by one of us in making a series of beryl analyses,† gave too low results for beryllium.

We have made a large number of separations by dissolving the mixed chlorides in the least possible excess of caustic soda, diluting the solution largely and precipitating the beryllium by boiling. This method has recently been proposed by Genth‡ as the most reliable of the known methods, and Baker§ used it successfully in his analysis of beryl. Before using the method in our own work we made a series of experiments to determine its accuracy and to find out the best conditions for making the separation. A standard solution of beryllium chloride was made from purified K_2BeF_4 containing ·1107 grams BeO in every 50 c.c. Our standard solution of aluminum chloride contained ·1002 grams Al_2O_3 in every 50 c.c. Neither of the solutions contained any alkali and not more than traces of sulphuric acid.

The method was as follows: 50 c.c. of each solution were measured into a platinum dish and evaporated to dryness, the chlorides were dissolved in the least possible quantity of water, and a rather strong solution of pure soda, made from metallic sodium, was cautiously added till the precipitate which at first formed was completely dissolved. The contents of the dish were then rinsed with cold water into a beaker containing about 800 c.c. of boiling water and the contents of the beaker boiled for one hour, replacing from time to time the water which evaporated. The beryllium separates out as a granular precipitate which is easy to filter and wash. After acidifying and concentrating the filtrate the alumina was precipitated with ammonia. Our experience has taught us that the best results are obtained by dissolving the dried chlorides in the least possible quantity of water and using as little soda as possible for dissolving the aluminum and beryllium.

Below we have given in tabulated form the results of our experiments.

* Proc. Amer. Phil. Society, xxi, 694, 1884. † Loc. cit.
‡ Loc. cit. § American Chem. Journal, vii, 175.

	Weight of Al_2O_3.	Weight of BeO.
	·1041	·1093
	·1057	·1080
		·1096
	·1045	·1099
		·1107
	·1032	·1093
	·1037	·1093
	·1031	·1083
Average	·1040	·1093
Standard	·1002	·1107

The precipitates were in all cases ignited for a long time to full redness over a ring burner. It will be seen that the BeO is quite constant and the average only a little below the standard. The Al_2O_3 is in all cases too high. If the quantity of mixed beryllium and aluminum oxides be determined in any compound, and then the BeO separated according to the above method and the Al_2O_3 determined by difference, the results will be very nearly correct. The determinations of Al_2O_3 and BeO in beryl given earlier in this article were made in this way.

To account for the excess of Al_2O_3 we thought that perhaps appreciable quantities of silica were dissolved from the glass by boiling the alkaline solutions of the mixed oxides for one hour. We therefore in every case dissolved the oxides in hydrochloric acid and deducted from their weight a slight quantity of insoluble matter amounting to about ·0010 grams in the Al_2O_3 and ·0004 grams in the BeO. The excess of Al_2O_3 must, therefore, have come from some other cause than silica dissolved from the glass. The alkaline solutions are so dilute that the glass is very little acted on, and determinations made in a platinum dish convinced us that the separation can be made just as well in beakers. We have concluded that the beryllium is not completely precipitated from a solution in soda by boiling and that it is not possible to wash out all of the soda from the precipitate. The following experiments on the determination of BeO in beryl will show this. The first column gives the weight of BeO obtained by boiling the soda solution, the second the same oxide dissolved in hydrochloric acid, reprecipitated with ammonia and ignited.

·1476	·1440
·1464	·1422
·1330	·1300
·4270	·4162

The total BeO in these experiments weighed ·4270 on first precipitation, ·4162 on second, a loss of ·0108. Calculating by

proportion the loss which would result from ·1107 grams BeO the quantity used in our first experiments we find

$$·4270 : ·1107 = ·0108 : x. \quad x = ·0027$$

that is, in the quantity of BeO which we used in making our experiments, the BeO was too heavy by about ·0027 grams, representing probably some soda compound which could not be removed by washing. The excess in the Al_2O_3 is due to the BeO which was not precipitated by boiling. If we take the sum of the Al_2O_3 and BeO in the average of our determinations ·2133 and deduct from it ·0027 we have ·2106 against ·2109, the sum of Al_2O_3 and BeO in our standard. The following determinations made from our standard solutions, the boiling of the soda solutions being done in platinum, confirm us in this. First weight of BeO ·1087 after solution and reprecipitation ·1068, weight of Al_2O_3 ·1041. ·1068 + ·1041 = ·2109, the weight of mixed oxides in our standard. We conclude therefore that the separation is not as perfect as our results would indicate. The error is however very constant, the amount of BeO which is not precipitated being almost exactly equal to the amount of soda which it seems impossible to remove from the precipitate by washing.

When phosphoric acid is present alumina may be separated from beryllium by boiling the solution of the mixed chlorides with barium hydroxide. The alumina goes readily into solution while the precipitate containing the barium phosphate and beryllium is easy to filter and wash. After dissolving the precipitate and separating the barium with sulphuric acid, a beryllium phosphate can be precipitated with ammonia. After weighing this the P_2O_5 may be determined by means of ammonium molybdate and the BeO by difference or the precipitate may be fused with sodium carbonate and the fusion soaked out with water which gives almost a complete separation of phosphoric acid from beryllium. If phosphoric acid is also to be determined it must be borne in mind that very perceptible quantities of it will be found in the barium sulphate precipitate.

We have also observed that when Al_2O_3 is ignited over a ring burner till a constant weight is obtained, then over a blast lamp there is a slight loss, amounting in the quantities which we have used in making the above experiments to about ·0010 grams. What this loss represents we are not able to say. Usually in practical work this error can not be avoided, because it is necessary to dissolve the ignited Al_2O_3 to test for traces of SiO_2 or iron, and it is almost impossible to dissolve Al_2O_3 which has been strongly ignited over a blast lamp. The same is true for ignited BeO. After strong ignition over a ring burner

there is still a loss of about ·0013 in the quantities which we used, by igniting for five minutes over a blast lamp. This may be done however, as the ignited BeO is readily soluble in hydrochloric acid.

In closing we wish to express our thanks to Messrs. Geo. J. Brush, L. Stadtmüller and Geo. F. Kunz for the rare material which they kindly furnished for carrying out this investigation.

Mineralogical Laboratory, Sheffield Scientific School, May 28th, 1886.

ART. XI.—*Communications from the U. S. Geological Survey, Division of the Rocky Mountains.* VIII. *On Ptilolite, a new Mineral;* by WHITMAN CROSS *and* L. G. EAKINS.*

THE mineral described beyond occurs in cavities of a more or less vesicular augite-andesite which is found in fragments at a certain geological horizon in the conglomerate beds of Green and Table Mountains, Jefferson County, Colorado. The formation to which this conglomerate belongs is of Tertiary age and will be described in the report upon the geology of the Denver coal-basin now in preparation by the U. S. Geological Survey. For the present article it is sufficient to say that the conglomerate in question is chiefly composed of worn pebbles and bowlders of andesitic rocks, embracing various types. The rock containing the new mineral has been found at several different places upon the mountain slopes, at approximately the same horizon in the series, and its fragments are not so worn and rounded as are those of other rocks in the conglomerate. Various structural modifications of this andesite have been found, ranging from the compact massive rock to that which is decidedly vesicular.

The massive rock is dull ashen-gray in color, exhibiting a few dark augite prisms and tabular feldspar crystals as the only macroscopic constituents. A microscopical examination shows the rock to consist of a network of small plagioclase microlites with irregular augite grains in very small quantity between them. In spots there seems to be a development of quartz in clusters of minute grains. No glassy base was seen, but certain yellowish globulitic masses are apparently devitrification products. Porphyritic crystals of augite, biotite and plagioclase are comparatively rare. Chemical analysis of the massive rock gave the following result:

* Read before the Colorado Scientific Society, May, 1886.

SiO_2	59·26
Al_2O_3	23·63
Fe_2O_3	·30
FeO	·57
CaO	5·93
MgO	·31
K_2O	4·78
Na_2O	4·94
H_2O	·74
	100·46

Analyst, L. G. Eakins.

The various porous or amygdaloidal fragments found evidently represent material from different positions in the original rock-mass, and according to the former position of each specimen there is a certain development of minerals in the vesicles or pores. A reddish-gray, finely cellular rock contains in some cavities creamy, banded opal, upon which a decided play of reddish color was noticed in certain spots. Chalcedony and quartz fill many cavities completely. Another rock specimen, in which the pores are all round and small, exhibits no minerals in its cavities. A third specimen is very porous, the pores being irregular though never greatly distorted. More than half of these cavities contain a banded deposit of opal and chalcedony, the banding having in all a parallel direction. A few pores are filled by clear chalcedony. All cavities not entirely filled in this manner show a crust of small, clear heulandite crystals of tabular form, with minute white globulitic masses of unknown character scattered over and between them. A still more porous rock in which the cavities are irregular shows traces only of the creamy opaline deposit, while heulandite and white globules of the unknown substance form a distinct crust. As a still more recent formation there appear in the pores of this rock small tufts of a white mineral. These are very delicate and could not be procured in sufficient quantity for chemical examination. The resemblance to mesolite, as it occurs in the basalt of Table Mountain, was so marked that for a time the identity of the two substances seemed possible, but these tufts belong to the new mineral, found more abundantly in other specimens.

On the north slope of Green Mountain there are fragments of this augite-andesite in some of which the white mineral in tufts is specially well developed. The rock is light reddish-gray and very vesicular, the pores being drawn out cylindrically in a certain direction. Many of these pores have been completely filled by a solid mass of chalcedony and quartz, the latter occupying the center. In other cavities there is merely a thin coat-

ing of pale bluish chalcedony, and upon this is deposited the above mentioned white mineral in most delicate tufts and spongy masses composed of short hair-like needles, loosely grouped together. These needles when examined under the microscope are found to be colorless, transparent prisms, the average diameter of which is less than 0·001^{mm}. The terminations of unbroken prisms are square, indicating the probable presence of a basal plane, parallel to which there are transverse fissures, as of cleavage. The extinction of the stouter prisms in polarized light is parallel to the prismatic axis, but the multitude of smaller ones are so delicate that they do not affect polarized light perceptibly.

In removing the mineral from the cavities, for chemical analysis, a small amount of chalcedony from the underlying coating, which scales off readily, was unavoidably mixed with the fine hairs. A separation was effected by throwing the unpowdered material into water and stirring, the spongy aggregates resolving readily into a cloud of minute white spicules which remained suspended while the solid particles of chalcedony with attached needles sank. After standing a few moments the supernatant liquid was poured off, this still containing in suspension the greater portion of the needles, which did not completely settle for several hours. Separation of the needles from other substances was thus made very complete and more than 0·5 gram of pure material secured for analysis. The result, with derived ratio, is as follows (L. G. Eakins):

SiO_2	70·35 ÷ 60 = 1·1725	or 10·06	or 10	
Al_2O_3	11·90 ÷ 102 = 0·1166	1·00	1	
CaO	3·87 ÷ 56 = 0·0691			
K_2O	2·83 ÷ 94 = 0·0301	1116	0·96	1
Na_2O	0·77 ÷ 62 = 0·0124			
H_2O	10·18 ÷ 18 = 0·5655	4·86	5	
	99·90			

Special care was taken with the water determination of the above analysis. The mineral began to lose water at a very low temperature and even on drying in the air bath at 100° C. there was a noticeable loss; the amount thus lost, however, was found to be regained upon exposure to the air, and before the analysis was made the material was allowed to remain loosely covered for several days.

The loss of water, beginning at 100° C., continued steadily until at a temperature between 300° and 350° C. all the water was expelled, and continued heating at full redness occasioned no further loss. No line of demarkation could be detected at which the loss temporarily ceased, to begin again at a higher temperature, and thus no ground would seem to exist for con-

sidering any definite portion of this water basic, although a high temperature is necessary for its total expulsion.

Heated before the blowpipe a tuft of the mineral shrinks considerably and fuses to clear glass. Hydrochloric acid, even boiling, has little or no action, but by strong sulphuric acid it is gradually decomposed. Of course in a mineral of this description a determination of hardness is impossible and one of specific gravity would be too inaccurate to be of any value.

We propose as the name for this mineral, *Ptilolite*, derived from *πτίλον*, *down*, in reference to the light, downy nature of its aggregates.

Referring to the molecular ratio derived from the analysis, it is seen that the empirical formula for this mineral is $RO, Al_2O_3, 10SiO_2+5H_2O$, R representing Ca, K_2 and Na_2. The substance belongs among the alumino-silicates of which no previously described hydrate contains so high a percentage of silica. Perhaps the nearest allied hydrous mineral is stilbite, the composition of which may be expressed by the formula $H_4CaAl_2Si_6O_{20}+4H_2O$.

While the structural formulæ for the complexer silicates are as yet hypothetical, it is of interest to note the place assumed by ptilolite in the scheme for the classification of the alumino-silicates adopted by Tschermak* and others. By the combination of the hydrous oxide $H_2Al_2O_4$ with two molecules of meta-silicic acid, H_2SiO_3, through the elimination of $2H_2O$, there results a simple alumino-silicic acid with the empirical formula $H_2Al_2Si_2O_8$. By combining the same hydroxide with 4, 6, 8, 10, etc., molecules of H_2SiO_3 there results a series of alumino-silicic acids, the following anhydrous salts of which are known:

$Na_2Al_2Si_3O_{10}$ in sodalite,
$K_2Al_2Si_4O_{12}$ as leucite,
$K_2Al_2Si_6O_{16}$ as orthoclase,
$Li_2Al_2Si_8O_{20}$ as petalite.

Other series are obtained by starting with other hydroxides of alumina.

Petalite stands alone in the above series as the representative of its type, and members with higher contents in silica are yet unknown. Now the zeolites are in many cases simply hydrates of the above or closely allied salts, although the water may be in part basic. No hydrate of petalite or of any corresponding salt is known, but ptilolite is found to be the hydrate of $RAl_2Si_{10}O_{24}$ which will be seen to be the next member in the above series, following petalite.

If such a classification of alumino-silicates be adopted, ptilolite must be considered as the first member of a new group of

* G. Tschermak, Lehrbuch der Mineralogie, 2te Aufl., 244, 438, 490.

hydrous minerals, and as R is composed of Ca, K_2 and Na_2 we can assume the possible existence of the pure lime, potash and soda compounds:

$$CaAl_2Si_{10}O_{24}+5H_2O$$
$$K_2Al_2Si_{10}O_{24}+5H_2O$$
$$Na_2Al_2Si_{10}O_{24}+5H_2O$$

The theoretical composition of an isomorphous mixture of these three compounds, in the ratio derived from the analysis of ptilolite, is given below in comparison with the analysis. The molecular weight of the mixed RO molecule was calculated to be 66·92.

	Calculated.	Found.	Difference.
SiO_2	69·86	70·35	+ 0·49
Al_2O_3	11·87	11·90	+ 0·03
CaO	4·04	3·87	− 0·17
K_2O	2·95	2·83	− 0·12
Na_2O	0·80	0·77	− 0·03
H_2O	10·48	10·18	− 0·30
	100·00	99·90	

The rare mineral milarite, although possessing a ratio RO : Al_2O_3=3 : 1, may yet be compared with ptilolite on account of its exceedingly high percentage in silica. Its formula is HK $Ca_2Al_2Si_{12}O_{30}$, requiring 72·66 per cent SiO_2.

ART. XII.—*Notes on the Peridotite of Elliot County, Kentucky;* by J. S. DILLER.

SEVERAL years ago Professor A. R. Crandall discovered two dikes of an interesting eruptive rock in eastern Kentucky, about seven miles southwest of Willard. The position of these dikes is well shown upon Professor Crandall's geological map of Elliot County.

A preliminary examination of the rock under the microscope revealed the fact that it belongs to the peridotites. These rocks are considered by most petrographers as eruptive, but there are others who regard them as of doubtful origin. One of the latest writers on petrography* divides rocks into two great classes: (1) those resulting from the accumulation of material transported from lower to higher levels (Anogene), and (2) those resulting from the accumulation of material transported from higher to lower levels (Katogene). The first group includes rocks of eruptive origin, while the second con-

* Elemente der Lithologie von Dr. Ernst Kalkowsky. 1886.

tains those derived from sedimentation. It is in the latter group that Kalkowsky places the peridotites. They nearly always occur intimately associated with highly altered rocks in regions of great disturbance, so that their relations cannot be readily determined. In eastern Kentucky, however, they are found with nearly horizontal unaltered sandstones and shales of the Carboniferous series and present such a promising opportunity for completely demonstrating the origin of peridotite that a more thorough examination has been undertaken.

The peridotite is a compact dark greenish rock with a specific gravity of 2·781. In it are embedded numerous grains of yellowish olivine uniformly distributed throughout the mass. Rarely it is fine-granular and dense like many dark colored basalts, but generally the grains of which it is composed are medium-sized. Occasionally the olivine grains wholly disappear and the deep green serpentine pervades the whole mass. Besides olivine and serpentine, which together form nearly seventy-five per cent of the rock, there are prominent grains of pyrope and ilmenite with a few scales of biotite.

The following table, showing the mineralogical composition of the peridotite, is based directly upon estimates made under the microscope of the areal distribution of the various minerals in the freshest portion of the sections taken from the locality where the peridotite is least altered.

Primary minerals.		Secondary minerals.	
Olivine	40 per cent.	Serpentine	30·7 per cent.
Pyrope	8 "	Dolomite	14 "
Biotite	1 "	Magnetite	2 "
Enstatite	1 "	Octahedrite	1·1 "
Ilmenite	2·2 "		
Apatite	*trace.*		

It is not claimed that this table represents with a high degree of accuracy the composition of the rock, but it closely approximates the real proportions in the sections studied. The table clearly indicates that originally at least eighty per cent of the peridotite was olivine, and that ultimately it will be nearly all serpentine, or perhaps in some places dolomite, with a small proportion of magnetite, ilmenite, pyrope and octahedrite.

The olivine generally occurs in the form of irregular grains held in the network of serpentine and other secondary products, but rarely, however, it is bounded by well defined crystallographic planes, a feature which is somewhat unusual for the olivine in peridotites. The crystals are short prisms terminated by brachydomes like those so commonly seen in basaltic lavas.

Enstatite plays so small a part among the minerals of this rock that it cannot be considered an essential constituent. It occurs in the form of irregular corroded grains with clouded

borders and is distributed throughout the mass with approximate uniformity.

Next to the olivine, pyrope is the most important constituent of the rock. It occurs in the form of spherical or elliptical grains varying from one to more than a dozen millimeters in diameter. They are found abundantly along the line of the dike in the soil resulting from its disintegration. The small clear deep red grains have a specific gravity of 3·673 and are locally regarded as rubies of problematical value. The most interesting feature of the pyrope is prominent under the microscope, where it is seen to be surrounded by a border of radial fibres exactly analogous to those described by Schrauf* as Kelyphite and later critically examined by A. von Lasaulx.† In this case the border is composed of several essentially different substances which are always present although varying much in proportions. First of these may be mentioned a dark powder of magnetite which is frequently so abundant upon the outer edge of the border as to render it opaque. The inner substance of the ring is of a grayish or reddish brown color and generally fibrous in structure, perpendicular to the periphery of the garnet. The fibres have occasionally very strong absorption in the direction of the longer axis and have nearly or quite parallel extinction, indicating that the mineral is biotite. This conclusion is completely demonstrated by a border in part of which the uniaxial, negative, strongly dichroic folia of biotite may be clearly discerned. The biotite extends far into the fissures of the garnet and evidently results from its alteration. Associated with it are small triangular and quadratic sections of a yellowish brown isotropic mineral, which in all probability is picotite. Lasaulx clearly demonstrated the presence of pyroxene and amphibole, in the so-called Kelyphite. Becke‡ and Kalkowsky§ pointed out the picotite but so far as I am aware the presence of biotite in this connection is here noted for the first time.

The ilmenite is readily distinguished from the magnetite even under the microscope in reflected light by the brilliant coaly luster of portions of its pitted surface. It occurs in large grains and not in the form of spongy particles like the magnetite. Under the microscope the ilmenite is frequently seen surrounded, penetrated, and even completely replaced, by a mixed group of yellowish and black grains, resulting from its alteration. The black opaque grains are magnetite, but the

* "Ueber die Umrindungen von Granat." Sitzungsberichte der Niederrhein-Gessell. zu Bonn. 1882, July 3.

† "Beiträge zur Kenntniss des Associations Kreises der Magnesiansilicate," Zeitschrift fur Krystallographie, 1882, vi, 321–388.

‡ Tschermak's Mineralog. und Petrographische Mittheilungen, iv, pp. 189, 285.

§ Elemente der Lithologie, p. 238.

yellowish ones are not as readily determined. They have a high index of refraction and are generally spherical, but occasionally their peripheries are straight and sharply defined, indicating crystallographic form. Such grains usually possess a higher degree of diaphaneity, and the sections are either triangular, square or diamond-shaped. The latter are most strongly doubly refracting, and extinction takes place parallel to the longest diagonal. No trace of cleavage could be discovered, but the facts enumerated render it highly probable that the mineral is octahedrite.

The relation of the peridotite to the Carboniferous sandstones and shales is of paramount importance in determining its age and origin. Only two reasonable hypotheses suggest themselves to my mind: (1) the peridotite may be older than the Carboniferous strata and formed on the floor of the sea a peak about which the horizontal strata were deposited; (2) the peridotite may have been erupted through the Carboniferous strata.

If the first hypothesis be correct we should expect to find the adjacent sandstone composed largely of detritus derived from the peridotite and to exhibit no evidence of contact metamorphism. On the other hand, if the second hypothesis be true there would not necessarily be a correspondence in the composition of the neighboring rocks and under favorable circumstances the sedimentary deposits would be metamorphosed near their contact with the eruptive. Chemical analyses 6 and 4 in the following table are of the adjacent sandstone and peridotite. The dissimilarity of the two rocks, both in chemical and in mineralogical composition, is so prominent as to at once dispel the thought that they are genetically connected. Although the exact contact of the two rocks was not exposed, hardened shale was found near the peridotite under such circumstances that its induration is certainly attributable to the influence of the eruptive mass. But this is not the strongest evidence, for the peridotite itself includes many fragments of shale which were picked up on its way to the surface. The contact metamorphism has resulted generally in the development of a micaceous mineral and the production from the shale of a rock such as has been designated spilosite. On the other hand, the peridotite itself has experienced endomorphic influences which resulted in the development to a very limited degree of a sphærolitic structure similar to that of the varioles in variolite.

The chemical analyses given in the following table were made with great care by T. M. Chatard, in the U. S. Geological Survey laboratory at Washington. The specific gravities were determined by the writer with a pycnometer in the case of the

olivine, pyrope and ilmenite; for the others, Westphal's specific gravity balance was used. Analysis 5 is of a fragment of syenite found upon the border of the peridotite and supposed either to have been brought up from a great depth by the

	Olivine. 1.	Pyrope. 2.	Ilmenite. 3.	Peridotite. 4.	Syenite. 5.	Calcareous S. S. near dike. 6.	Fine grained fissile S. S. near dike. 7.	Indurated shale near dike. 8.	Fragment of slate included in peridotite. 9.
Water at 110° (H_2O)	0·14	0·17	0·20	8·92	0·51	0·85	1·94		1·40
Water at red heat (H_2O)	0·66					2·32	5·17	8·78	9·00
Carbonic acid (Co_2)				6·66		6·29		0·55	0·88
Silica (SiO_2)	40·05	41·32	0·76	29·81	60·56	60.78	60·25	41·32	35·53
Titanic oxide (TiO_2)	0·07	0·16	49·32	2·20	1·19	0·03	0·23	0·48	0·95
Phosphoric acid (P_2O_5)	0·04	none	trace	0·35	0·30	0·09	0·10	0·08	0·08
Chromic acid (Cr_2O_3)	0·24	0·91	0·74	0·43				trace	
Alumina (Al_2O_3)	0·39	21·21	2·84	2·01	16·19	10·54	23·18	20·71	18·23
Ferric oxide (Fe_2O_3)	2·36	4·21	9·13	5·16	5·19	3·27	1·53	2·59	2·46
Ferrous oxide (FeO)	7·14	7·93	27·81	4·35	2·41		3·42	5·46	4·81
Manganous oxide (MnO)	0·20	0·34	0·20	0·23	0·36	0·10	0·10	0·17	0·13
Nickel oxide (NiO)	Co0 = trace			0·05					
Lime (CaO)	1·16	4·94	0·23	7·69	2·09	10·15	0·51	9·91	21·17
Magnesia (MgO)	48·68	19·32	8·68	32·41	1·30	1·59	3·52	1·91	2·01
Potash (K_2O)	0·21	}	}	0·20	4·82	2·36	3·17	0·88	1·08
Soda (Na_2O)	0·08	{ 0·07	{ 0·19	0·11	4·78	1·41	0·39	7·19	2·53
Sulphur (S)				none					
Sulphurous acid (SO_2)				0·28					
Total	99·42	100·58	100·10	100·86	99·70	99·78	100·51	100·03	100·26
Specific gravity	3·377	3·673	4·453	2·781	2·633				2·489

peridotite or else to have reached the surface by an independent eruption of syenite. A fragment of granulitic rock was also included in the peridotite, and that the latter is a truly eruptive rock which traverses many thousand feet of Paleozoic strata to reach the surface is a matter which does not admit of reasonable doubt.

U. S. Geol. Survey Office, Washington, D. C., March 29, 1886.

Art. XIII.—*Temperature Observations at the Lake Superior Copper Mines;** by H. A. Wheeler.

The copper mines of Keweenaw Point, Lake Superior, have attained such depth, as the result of the rapid prosecution of successful mining, that some of them are now among the deepest mines in this country. They therefore present an ex-

* Presented before the St. Louis Academy of Sciences.

cellent opportunity for obtaining data as to the rate of thermal increase with descent into the earth. While the usual thermic gradient is between 50 to 55 feet for an increase in temperature of 1° F., exceptional gradients, both much higher as well as lower than this, have been obtained in certain localities. It was to add the evidence of this region in respect to this phenomenon, which is of economic as well as geological importance, that the writer made the following observations in some of the deeper mines of this now quite old mining district.

Keweenaw Point is a tapering peninsula that boldly extends in a general northeasterly direction out into the middle of Lake Superior, from its southern shore, for a distance of some 70 miles. It essentially consists of a series of parallel belts of fragmental and plutonic rocks that abut against sandstone, of supposed Potsdam age, on the eastern side, while they are conformably overlaid by sandstones and shales of Lower Silurian age on the western side. The plutonic rocks consist of amygdaloidal and compact melaphyres and diabase, while the intercalated fragmental rocks comprise numerous belts of a red conglomerate, the pebbles of which consist largely of quartz porphyry. These conformable belts have a dip of about 55° with a nearly northerly strike at the southern end, and gradually become flatter, and veer around until, at the extremity of the Point, at their northern end, the dip is only 20° and the strike easterly. The fractures incident to such a bending of the formation has resulted in fissures, in which some of the older mines are located, that are filled with zeolitic and other mineral matter and often are richly charged with copper.

Most of the mines are in either the melaphyre or conglomerate belts, in which the copper occurs disseminated in grains and masses in the native condition. The whole area is more or less thickly overlaid with glacial drift which in some cases is over 100 feet thick. The temperature observations were made during a rapid trip and the depths noted were taken from the mines, maps and other data obtained on the premises. Special care was taken to avoid modifying conditions at the observing stations, such as draughts, water, working places, etc., while duplicate readings were made of the thermometer. While the results obtained can scarcely claim to be more than close approximations, and are liable to be modified by more accurate and extended observations, they clearly show that the thermic gradient in this region is one of the lowest that has ever been noted; and the variations in the different mine seems to indicate the cause for this very low rate. The results of the observations are given in the following table:

Mine.	Thermal increase in feet for 1 degree Farenheit.	Vertical depth of mine in feet.	Distance between rating stations in feet.	Highest temperature of mine (Farenheit).	Character of "Lode."
Atlantic ----	99·5	907·	796·	51·6°	Melaphyre.
Central -----	101·	1950·	1860·	61·	Fissure vein.
Conglomerate	95·	617.	527·	48·3	Quartz prophyry Conglomerate.
Osceola -----	76·5	996·	860·	54·5	Melaphyre.
Tamarack ---	(110 7)	2240·	2104·	62·	Quartz prophyry Conglomerate.
Quincy -----	122·	1931·	1820·	58·5	Melaphyre.
Average --	100·8*				

Of these observations, those at the *Atlantic* mine were made under very favorable circumstances and this particular rate of practically 100 feet to 1°, was closely checked by other determinations made on intermediate levels. In finding the rate for this mine, as in all other cases, as great a distance as possible was obtained between the two rating stations, while the upper station was always taken so far below the surface as to be beyond the influence of solar heat. The mine is about 2 miles south of Portage Lake, which is a narrow, long arm of Lake Superior.

The *Conglomerate* mine is about 36 miles northeast of the Atlantic mine, as measured along the formation, and like the Atlantic at the southern end, is at the other extreme of the series of mines examined, the others being between these two. It is in a belt of conglomerate, and is 3 miles distant from the shore of Lake Superior.

The *Central* mine is on a narrow fissure vein and is about 2½ miles distant from the Lake Superior shore line.

The *Osceola* mine is nearly 5 miles from the western shore line of Lake Superior and 4 miles from that of Torch Lake on the east side, the latter being a land-locked arm of the main lake. The rate determined on for this is the average of five different, closely agreeing rates, established between different levels of the mine. The observations made in this and the Tamarack mine were kindly volunteered by Mr. Frank Klepetko, the mining engineer of the company.

The *Tamarack* mine, unfortunately, did not furnish stations that could be regarded as reliable, as they were too close to active mining operations, and my notes show that the effect of the presence of miners, with their lights, blasting and rock-drills (worked by compressed air) give very erroneous results, especially the rock-drills with their ice-cold exhaust. So while I give the results of this mine, they are not to be accepted as satisfactory; this mine is 4 miles from Lake Superior.

* With the "Tamarack" rate omitted, the average thermic gradient is 99· feet to the degree.

The *Quincy* mine is less than a mile from Portage Lake; in fact some of the workings on the vein extend nearly to the lake-side, while the melaphyre belt that the mine works crosses the lake. The mine workings, though now very much below the bottom of the lake, are quite free from water, the little they have being mostly of surface origin.

It is to this fact of the proximity of the mines to the cold waters of Lake Superior, that I wish to draw the reader's attention. For so far as I have been able to gather similar data, I have not found another instance where such very low thermic gradients have been observed, with the single exception of the Dukinfield Coal Pit, near Manchester, England, where a gradient of 90 feet to the degree is recorded. As no details were given with this, it is impossible to say whether this is the normal gradient for that region, or whether modifying influences, like an excessive influx of water, or other causes, may have made this simply a local rate. While the average rate of these copper mines is most exceptionally low and noteworthy, having quite possibly the lowest thermic gradient on record, the variations among the different mines is quite striking. In accounting for it, it should be stated that there is no reason to suspect that the observations of any one mine (with the exception of the Tamarack) are any less trustworthy than another. Nor does the nature of the rock in which the mine is worked seem to offer an explanation, for while three quite different classes of "lodes" are presented, the greatest variations occur in those whose characters are identical, to wit: the Atlantic, Osceola and Quincy, which are all in melaphyre. Though each of these mines is on a different belt of melaphyre, the general character of the entire formation is quite similar and alike, or a series of conformable, parallel belts of alternating conglomerates, melaphyres and diabase. The mines are quite similar in respect to freedom from water, all being comparatively dry mines, considering their extensive character, and what little water they have to contend with is quite generally of surface origin. In the mines mentioned there is at present no evidence of active chemical changes or reactions observable to cause this differentiation, while the general system of mining with rock-drills is carried on in all of them.

But when we consider their relation to one another as regards their proximity to Lake Superior, we are at once impressed by the close relationship between this distance and the thermic gradient; the mines nearest to the lake shore have the lowest gradient, while those farthest away have the higher or more rapid rate. When we consider the magnitude of Lake Superior and remember that only its surface waters change in temperature, as the great body of its deep waters remain con-

stantly at the temperature of maximum density or 38·8° F.; and when we recall the excellent conducting power of water as regards heat, the influence of this great enveloping body of cold water can be at once appreciated. And it is primarily to it acting as a great cold blanket, that the writer attributes the general coolness of the rocks in this region, and secondarily in accounting for the local variations in the thermic gradient of the different mines. The nearer the mines are to this great cooling influence, the lower the thermic gradient will be found to be, while the farther one goes away the less will its influence be felt, until, should we pass entirely beyond such influence, we should probably get the very general and usual gradient of 50 to 55 feet. That such is the case seems to be indicated by the observations cited, and this is the theory offered by the writer. None of the mines mentioned are so distant from the cold body of lake water but that, notwithstanding the much smaller efficiency of rock-formations as heat conductors, they still show the effect of its strong influence. While the Osceola mine, with nearly 5 miles intervening between it and the main lake, shows that this thickness of rock-mass moderates very appreciably the refrigerating action of the lake it also indicates that, perhaps at a distance of 7 or 8 miles from the lake, such a thickness of rock-mass would render its effect inappreciable, and we should again have the normal gradient.

ART. XIV.—*An Application of the Copper Reduction Test to the Quantitative Determination of Arsenic;* by HENRY CARMICHAEL, Ph.D.

ONE milligram of arsenious oxide added to strong chlorhydric acid and digested at the boiling temperature with a clean polished piece of copper having a surface of forty square millimeters imparts to the copper a grayish tint without fully extinguishing the red color of that metal. The color darkens rapidly if a larger quantity of arsenious oxide is supplied, and if the copper is removed as soon as it has assumed a steel gray tint, it will be found that a milligram and a quarter of the oxide has been removed from solution. The transition from reddish gray to steel gray is so marked that the experimenter can readily match a specimen which has been selected as the standard of color.

As the arsenic compounds react more slowly and with less certainty, they should always be reduced to the -ous equivalent by means of sulphurous oxide before the trial is made. Using a standard square of copper as an indicator, the writer has been led to the adoption of a method which is believed to be, for the

estimation of small quantities of arsenic, quicker, simpler, easier, more delicate, and, in the hands of toxicologists, less exposed to fallacy than any other.

A smooth, polished sheet of pure copper, not thicker than $0{\cdot}05^{mm}$, is selected. As the commercial article is usually varnished, it must be cleaned with alcohol or otherwise. A neglect of this precaution is indicated by the irregularity of the arsenical deposit. The copper is cut into pieces 20×21^{mm}. A strip one mm. wide is cut nearly across the longer side of each, and bent at a right angle to the general surface. These are the normal squares, and the bent strips are the handles by which they are manipulated. In applying the method, if the arsenic is possibly present in the substance under examination as an arsenic compound, it is digested with strong sulphuric acid, the solution reduced to a small volume, and after the conversion of the arsenic into arsenious oxide, strong chlorhydric acid is added. If the substance can only contain arsenic in the arsenious form, it is reduced to a small volume if liquid and strongly acidulated with HCl.

The acidulated solution is brought into a small porcelain capsule and a square of copper introduced. The capsule is placed over a small flame, and the square moved back and forth until it has acquired the tint of the standard chosen. The copper is removed, carefully washed and dried. The strength of acid is maintained by occasional additions, and squares are made to succeed one another until there is no further discoloration. The last square is usually lighter than the normal. Multiply the number of squares by the volume of standard arsenious solution which is necessary in coloring equally a single square, and subtract an amount which it is shown by trial the last square has required less than a normal square, and the total amount is given. By altering the concentration, the acidity, or the temperature, the rate of deposition is readily controlled. Two examples will illustrate the method.

(*a.*) A square of wall paper two inches on a side was placed in a capsule and drenched with strong HCl. A small flame was brought under capsule and squares of copper were successively colored to the standard until the exhaustion of the arsenic was marked by the lighter color of a surface long exposed to the acid liquid. The last was matched by a square which was known to have withdrawn $0{\cdot}13^{mgrm}$ and the other five by a square which had withdrawn $0{\cdot}23^{mgrm}$. The total amount, therefore, to the square yard of paper was $414{\cdot}7^{mgrm}$. of arsenious oxide. The analysis, which consumed but a few minutes, was qualitative as well as quantitative. It may be of interest to state that the paper was "warranted strictly free from arsenic."

(*b.*) A human stomach sent for analysis was, after the usual physical examination, quartered. The part taken in the search for inorganic poisons was cut into small pieces and the organic matter destroyed with HCl and $KClO_3$ as usual. Through the filtered solution, which had been partially evaporated, SO_2 was passed and the excess removed. H_2S was passed through the warm solution for twelve hours. The precipitate was thrown on a small filter, and after thorough washing was drenched with NH_4HO. The filtrate was evaporated in small capsule, twice moistened with concentrated HNO at a steam heat, then moistened with fuming sulphuric acid and heated over direct flame until the unoxidized sulphur had run into a single globule and the organic matter had been charred. A little warm water was added, a few bubbles of SO_2 passed through the solution, and the excess removed. Concentrated HCl was added and normal squares successively coated. The total amount of arsenic in the stomach was computed to have been $2{\cdot}76^{mgrm}$.

For verification one square was cut into narrow strips and pushed into a hard glass tube of the size of a quill. One end of the tube had previously been drawn down to a diameter of one mm. and the opposite end, after the introduction of the copper, was sealed with a mouth blowpipe. The bottle-shaped tube thus formed was placed in an air-bath for the expulsion of moisture and the bulb then raised to redness over a small flame. A white cloud formed and condensed in the neck. The sublimate was easily vaporized and driven from point to point. Under the microscope the coating appeared as an aggregation of sharply defined, highly refracting, regular octahedrons. The tube was sealed for future reference. The neck of a second tube, prepared in the same manner, was broken off and the arsenious oxide converted into the sulphide in a current of H_2S. The total exhibit then consisted of:

(1.) A steel gray film on copper which did not rub bright.

(2.) Highly refractive, regular octahedrons produced by the oxidation of said film and by sublimation, and which were easily vaporized, reforming as octahedrons.

(3.) A bright yellow substance formed by the action of H_2S upon the octahedral sublimate.

Confirmatory tests might easily have been applied, but the writer, having taken the customary precautions in testing purity of chemicals and utensils, considered the proof of arsenic pre-existing in the material submitted for examination as abundant, and is of the opinion that such proof would, in similar cases, be only weakened and obscured by the employment of Marsh's or other familiar tests.

When the above method was first under trial, and it was not known how much the deposition of the steel gray film was influenced by foreign substances, the course of procedure was as follows:

The arsenious liquid under examination was placed in a burette and fed from this into the capsule containing hot chlorhydric acid and a copper square. After the exhaustion of the arsenic by the successive introduction of squares, the burette was filled with a standard solution of As_2O_3 (1 : 10,000), and this solution fed into the same liquid until the same number of squares were covered. The amount of arsenious oxide was then read directly from the burette. Theoretically superior, the results hardly excel in accuracy the results of the preceding method, while the time and care required are greater.

As a matter of curiosity it may be stated that a copper square one mm. on a side is capable of disclosing and estimating ·0000025 grm. arsenious oxide, a quantity four hundred times less than that necessary for turning the beam of the ordinary chemical balance.

The above quantitative method is commended for trial as being in the hands of experts free from fallacy; requiring few chemicals and utensils; not interfering with the search for other organic poisons and not interfered with by ordinary impurities, and as intelligible to the ordinary juryman, notwithstanding the quibbles of counsel.

Brunswick, Me., April 19, 1886.

Art. XV.—*On the Crystallization of Gold;* by Edward S. Dana.

The attention of the writer has been directed recently to some specimens of crystallized native gold offering several points of interest and novelty. The crystallization of the native metals, gold, silver and copper, is a subject of more than usual difficulty, and for our knowledge in this direction we are largely indebted to the excellent work of Rose.* More recently vom Rath has made an important contribution in regard to the complex crystallized plates and thread-like forms of gold; Helmhacker† has described the interesting gold crystals from Sysertsk;‡ while v. Jeremejew,§ Lewis,‖ Fletcher¶ and Werner** have added to the list of observed forms.

* Pogg. Ann., xxiii, 196, 1831; Reise nach dem Ural, i. 198, 1837, *et al.*
† Zeitsch Kryst., i, 1, 1877. ‡ Tschermak's Mineral. Mittheilungen, 1877, 1.
§ Verh. Min. Ges. St. Petersburg, II, v, 402, 1870.
‖ Phil. Mag., v, iii, 456, 1877. ¶ Ibid., ix, 1880. ** Jahrb. Min., i, 1, 1881

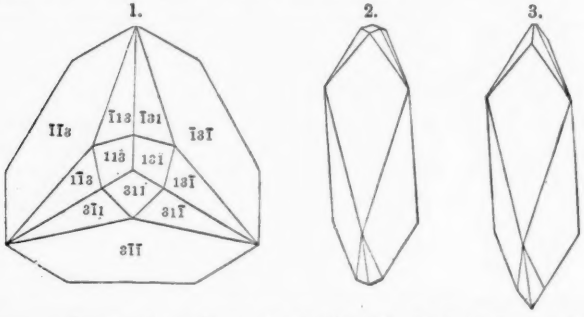
1. *Gold from Oregon.*

The delicate crystalline threads and arborescent forms of the gold from the White Bull mine in Oregon have long been a prominent ornament of collections, especially in America, but, so far as the writer is informed, no attempt has been made to describe them. A brief sentence is devoted to the subject in his Text-Book of Mineralogy, but the statement there is only partially correct.

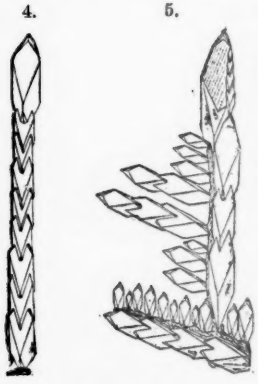
The beauty and delicacy of these forms are perhaps unrivaled in the species, but to decipher them crystallographically does not seem at first to be especially easy. If examined superficially the threads appear to be made up of acute rhombohedral forms, closely crowded upon each other. The terminal crystal, which is in many cases much the largest of the series, usually shows also the presence of a six-sided pyramid at the apex, a form often only faintly indicated in the other crystals. In rare cases, where this terminal crystal is unusually well developed, close examination reveals also the presence of three other minute planes forming an obtuse termination to the hexagonal pyramid. The position of these planes at once suggests an explanation of the form, and a few measurements show that this explanation is the correct one. The planes observed are all those of the tetragonal trisoctahedron 3-3 (311), common in the species, and the peculiar appearance and apparent rhombohedral symmetry are due to the fact that the crystals are uniformly elongated in the direction of the octahedral or trigonal axis.

This is then simply a case of pseudo-symmetry, analogous to that by which a regular octahedron may be transformed into a rhombohedron with prominent basal plane, or into a simple acute rhombohedron if these two planes are suppressed; or again, to that in which a rhombic dodecahedron becomes a hexagonal prism terminated by rhombohedral planes; or, still again, like that which turns the trisoctahedron 2-2 (211) into a combination of an obtuse rhomhohedron, a scalenohedron and a hexagonal prism. These are cases that have been long recognized. The case now described is remarkable for the regularity of the resulting forms and the way in which they are combined. This tendency in nature to thus imitate the symmetry of one system by the development of crystals belonging to another system, is in part explained by the fact that the planes whether referred to the one system or the other, have in either case rational symbols. Thus if we place a cube with its trigonal axis vertical, and regard it as the fundamental rhombohedron with a rhombohedral angle of 90°, the planes of the trisoctahedron 3-3 group themselves as follows (figs. 1, 2 and 3).

The planes 113, 311, 131, with the three opposite, form an obtuse rhombohedron with the symbol $\frac{3}{5}$-R (20$\bar{2}$5) and having a terminal angle (supplement) of 50° 29′. The six adjoining planes, 1$\bar{1}$3, 3$\bar{1}$1, 31$\bar{1}$, 13$\bar{1}$, $\bar{1}$31, $\bar{1}$13, with their opposites, form a hexagonal pyramid of the second series, with the symbol $\frac{4}{3}$-2 (22$\bar{4}$3); the terminal angle is here 50° 29′ and the basal angle 62° 58′. The six remaining planes of the twenty-four, namely $\bar{1}\bar{1}$3, 3$\bar{1}\bar{1}$, $\bar{1}$3$\bar{1}$, and those opposite, form an acute rhombohedron with a symbol $4R$ (40$\bar{4}$1), and a terminal angle of 117° 2′.



The predominating form is uniformly this last mentioned acute rhombohedron; though traces of the pyramid can usually be seen. The simple crystalline threads are built up of a series of these rhombohedrons in parallel position and crowded closely together. This is shown in fig 4. The terminal crystal is often larger than the others, and frequently of the skeleton type with prominent salient edges and the larger part of the face depressed, and perhaps made up of a series of fine parallel wires of frosted gold, suggesting some of the most delicate ornaments made by a skillful worker in gold.



The threads, however, are not limited to a single line of parallel crystals; generally there are two lines close together with a depressed furrow between them, and a third in which the crystals are also in parallel position with each other, but elongated according to another octahedral axis. In these last cases each plane of a crystal in one line is parallel to one in the other, but these planes have a different value in the rhombohedral development. Figure 5 shows a string of these crystals

branching off from another line at the bottom; here the second line of crystals parallel to the first is concealed from view, but the third is shown consisting of those elongated in the direction of the other axis. These last are represented as having the same rhombohedral development as the others, which is often true, but it is also common to find them with this elongation scarcely shown so that they deviate much less from the ordinary trisoctahedral form. These threads are then made up of the line or lines of sharp rhombohedral forms and this other line of minute bead-like crystals. These compound threads often taper down to a fine wire with crystalline markings on the surface but showing no distinct forms.

No fullness of description could give a satisfactory idea of the variety of these forms, as no drawing could adequately represent their beauty and delicacy. The arborescent branching forms are the most beautiful. Here we pass from examples where from a single stem a series of little lines run off, to others where the branching is again repeated, and yet again with such perfection that each individual crystal can be clearly made out. Other forms take the shape of a feather with a strongly defined central axis and with the fine threads branching from it on both sides at a slightly oblique angle ($o \wedge o = 70° 32'$). The central line is here normal to a plane 111, while the branches go off in directions normal to $1\bar{1}1$ and $\bar{1}11$ respectively; in all cases we have to do with parallel grouping only, and there is no necessity to appeal to twinning to explain the forms observed. The only distinct examples of this method of growth in gold, which the author has been able to observe, are these from the Oregon mine, with the exception of a single Hungarian specimen in the cabinet of Mr. Clarence S. Bement of Philadelphia, which appears to be developed in a similar manner.

2. *Gold from California.*

The gold mines of California have produced large numbers of specimens of finely crystallized gold, but unfortunately it is only rarely that they have been preserved. But little has been published upon the subject; a recent article somewhat popular in character, by W. P. Blake* of New Haven, is deserving of mention. The specimen to which the writer's attention was first directed belongs to the Yale collection, and is labeled as having come from Tuolumne County. It consists of a series of octahedrons in parallel position, and passing from the small solid crystals to larger ones with cavernous faces and their edges in ridges, and then to others looking as if they had been made of bent wire. In addition to the large octahedral faces (o), there

* The various forms in which gold occurs in nature, 25 pp.; from the Report of the Director of the U. S. Mint for 1884.

are also prominent those of the trisoctahedron 3·3 (*m*), usually strongly striated; a hexoctahedron, one set of whose edges are apparently truncated by the trisoctahedron and traces of a second hexoctahedron. The determination of this first mentioned hexoctahedron, as will be seen, requires exact measurements, and on all the larger crystals the planes are not bright enough to be used on the goniometer. A single very small crystal ($\frac{1}{8}^{mm}$ across) was found, however, on which these faces were brilliant though excessively minute. On this the three angles of the hexoctahedron were measured (with the usual compound goniometer), as also the inclination of a face upon the adjacent octahedral and trisoctahedral faces. Two independent measurements for different faces were obtained in each case. These measurements are liable to an error of from 5′ to 10′ in consequence of the want of sharpness of the images obtained, but they are accurate enough to prove beyond all question that the true symbol is 18-$\frac{2}{3}$ (18·10·1). This will be seen from the following comparison of measured and calculated angles:

	Edge A. 18·10·1 ∧ 18·1·10	Edge B. 18·1·10 ∧ 18·1·10	Edge C. 18·10·1 ∧ 10·18·1
Meas.	35° 50′, 36° 9′	5° 43′, 5° 41′	31° 53′, 32° 1′
Calc.....	35° 58′	5° 34′	31° 51′

	x o 18·10·1 ∧ 111	*x m* 18·10·1 ∧ 311
Meas.	35° 44′, 35° 45′	18° 2′, 18° 10′
Calc.	35° 41′	18° 4½′

It will be seen that the agreement between measured and calculated angles is remarkably close, considering the nature of the faces. The goniometer also showed, independently of the calculations, that the trisoctahedral planes do not actually truncate the edges of the hexoctahedron, although the planes 18·10·1, 311, 10·18·1 do fall very nearly in a zone.

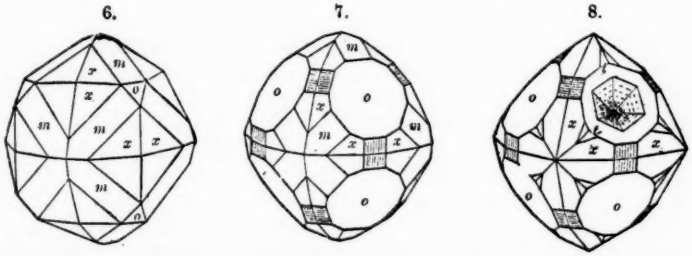
The positive determination of the form is of some interest, both because it is so common in the California crystals, as will be noted later, and because it was observed by Rose on specimens from the Ural many years ago. In his paper, already referred to, he remarks upon the occurrence of a hexoctahedron in conjunction with the dodecahedron, octahedron, trisoctahedron 3·3 and the hexoctahedron 4·2; he gives several figures, one of which has been copied in Dana's Mineralogy (f. 53, p. 3). The crystals examined by Rose* afforded only rough measurements, and to the symbol obtained 19-$\frac{19}{11}$ (19·11·1) he consequently did not attach very great importance.

*Rose uses the letters *t* for this hexoctahedron and *n* for 4–2; the writer, following Miller, restricts the letter *m* to 3–3, *t* to 4–2, and uses *x* for the hexoctahedron 18-$\frac{2}{3}$.

It was suggested by Naumann,* that 15-$\frac{5}{3}$ (15·9·1) was a more probable symbol, since it satisfied the measured angles about as well as the other, and at the same time was a form whose edges (A) were truncated by the common trisoctahedron 3-3 (311). This suggestion Rose was inclined to accept, and later writers have followed him (e. g. Klein).† A comparison between Rose's angles and those required by the form 18-$\frac{9}{5}$ (18·10·1), positively determined on the California crystals, leaves no doubt that the latter symbol should also be given to Rose's plane since it satisfies the measured angles as well or better than either of the others suggested.

	Calculated. Edge B.		Measured. Rose.
For 19-$\frac{19}{11}$	15-$\frac{5}{3}$	18-$\frac{9}{5}$	
5° 13′	6° 33′	5° 34′	5° 10 to 5° 41′
Inclination on *o* (111)			
35° 28′	34° 32′	35° 41½	36° 50′ to 37° 10′
On *d* (110)			
15° 9′	14° 24′	16° 11′	15° 30′ to 15° 50′

This is an interesting example of a case in which the so-called zonal law, so often employed to decide a doubtful symbol



does not hold good. Figure 6 shows one form of the crystals now being described; another is given in figure 7 which also exhibits an additional point of interest. The octahedral edge is here, in some cases, apparently truncated by the dodecahedral plane, in others beveled by a pair of planes; closer inspection, however, shows that this edge is formed simply by an oscillatory combination of the adjacent planes of the hexoctahedron. In other crystals of more octahedral habit the edges are all thus finely striated. The faces of the trisoctahedron *m* are also, though not always, striated in a similar manner, and sometimes the place of the plane seems to be taken by this oscillatory combination of the hexoctahedral planes.

This hexoctahedron *x*, 18-$\frac{9}{5}$, appears to be a common form

* Pogg. Ann., xxiv, 385. † Jahrb. Min., 1872, 129.

in the California gold. A beautiful specimen in the cabinet of Professor Brush from the Spanish Dry Diggings in El Dorado county shows it very plainly. This specimen consists of large crystalline plates bound together by a little quartz; the plates are in part solid with triangular markings on the surface, or hexagonal depressions made by the planes of this hexoctahedron, and in part consist of open work formed of delicate crystalline ribs branching at angles of 60° and 120°. These plates are essentially flattened octahedrons, and their edges are all formed by an oscillatory combination of the hexoctahedral planes, producing a fine striation similar to that on the specimen before described. Occasionally the edge is beaded with distinct crystals, and in cavities other crystals are to be seen, the small ones entire, or at most, with hexagonal pittings (figure 8), the larger ones, skeleton forms, as if formed of gold wire. Measurement proved the hexoctahedron to be the same as that already determined, while a second hexoctahedron *t*, 4-2 (421) is sometimes sufficiently developed to admit of determination.

The writer has recently had an opportunity to examine the fine series of crystallized gold in the cabinet of Mr. C. S. Bement of Philadelphia, and has observed a number of specimens showing the hexoctahedron 18-$\frac{9}{2}$ and very similar in habit to those described. Two of these specimens were from El Dorado county; another from Tuolumne county was octahedral in habit with the edges replaced in the manner described by the oscillations of *x*; still another from Yreka county showed several thin triangular plates with the striations on the edges, and with also hexagonal pittings formed by the planes of the same hexoctahedron. In the article by Prof. Blake, already alluded to, a description is given with figures of octahedral gold crystals, similar in form to those here mentioned. These crystals were from the Princeton mine in Mariposa county, and they agree so closely in form and habit with those here figured as to leave no doubt that the planes, if determined by measurement, would be found to have the same symbols.

Art. XVI.—*Classification of the Cambrian System of North America;** by Charles D. Walcott.

The formations included within the Cambrian system, in this paper, are those characterized by the predominence of the types of the "First Fauna"† of Barrande and such additional

* Read before the National Academy of Science at Washington, D. C., April 23d, 1886.

† The "First" or "Primordial Fauna" of Barrande, as found in North America, is characterized by a trilobitic fauna which, in the presence of the genera Agnostus, Paradoxides, Olenellus, Dicellocephalus, Ptychoparia and their allied genera, distinguishes it from the succeeding Lower Silurian (Ordovician) fauna.

strata, not characterized by the presence of fossils, as are stratigraphically and structurally connected with Cambrian strata identified by organic remains.

Professor Geikie, in the last edition of his Manual of Geology (1885, p. 65), has included the Cambrian as a subdivision of the Silurian system. I do not *now* wish to question the wisdom of this for the geologic section as it occurs in England and the Continent; but of the presence of a well-defined geologic system beneath the Lower Silurian (Ordovician) strata characterized by the Second fauna of Barrande, or the Trenton fauna (including the Upper Calciferous) on the North American continent, there is little doubt. The geologic sections, given in this paper, show that it has a total thickness of over 18,000 feet and contains a known fauna of 92 genera, including 393 species; that but very few of these species pass up into the Calciferous horizon of the Lower Silurian (Ordovician), and that the faunas of the two systems are so distinct in their general facies and also in detail, that they are quite as readily separated as the Lower and Upper Silurian, Silurian and Devonian, or Devonian and Carboniferous faunas. There is no doubt that in certain areas the faunas of the Cambrian and Lower Silurian (Ordovician) systems are intermingled in the passage beds between the two systems, but the same is more or less true of all the great divisions of the entire geologic series, from the Archean to the Quaternary.

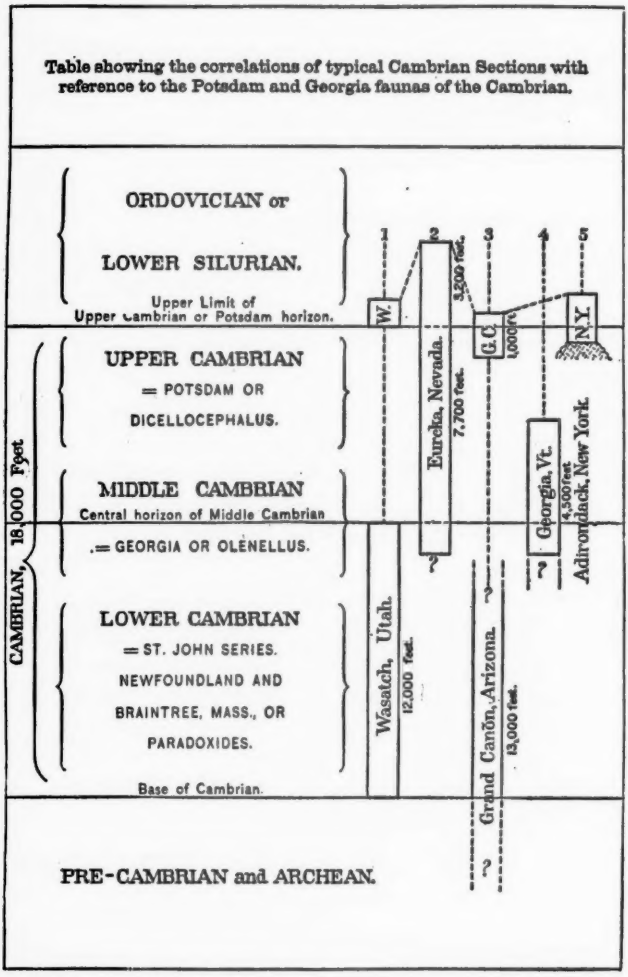
Strata of the Cambrian System.

In beginning the study of the Cambrian system, I looked for well-defined Paleontologic horizons with relation to which the various local sections and their contained faunas could be compared. It was evident that the Potsdam faunas of New York and the Mississippi Valley were at or near the summit of the Cambrian, but further than that there was little data. Mr. E. Billings called the Georgia or Olenellus fauna "Lower Potsdam," and considered the Paradoxides fauna as of older date: but, as late as 1885, one of our best-known paleontologists wrote: "my own impression, at the present, is that the New York typical Potsdam is about equivalent to the lower portion of the Wisconsin areas, and that the Acadian beds of Canada and Vermont, and perhaps the other Atlantic areas, are not appreciably different in age, but that the difference in faunas is more the result of conditions upon which life depended than a difference in time." (Bull. Amer. Mus. Nat. Hist., vol. i, p. 140, 1885.)

The results of the study of the Middle Cambrian faunas will appear in Bulletin 30, of the U. S. Geological Survey, and I have taken much of the data of this paper from the introduc-

tion of that bulletin. In establishing the stratigraphic position and paleontologic characters of the Georgia or Olenellus fauna of the Middle Cambrian, the key to the succession of the Cambrian faunas was obtained, and the sections that are correlated

1.



in the diagram (fig. 1) are placed on the general section with relation to the stratigraphic position of Olenellus and Dicellocephalus, or Georgia and Potsdam faunas.

The first section (fig. 2) to which I wish to direct your attention is that of the Wasatch Mountains, in Utah, where the Cambrian is well shown in Big Cottonwood Cañon. The section is described in the reports of the Geologists of the

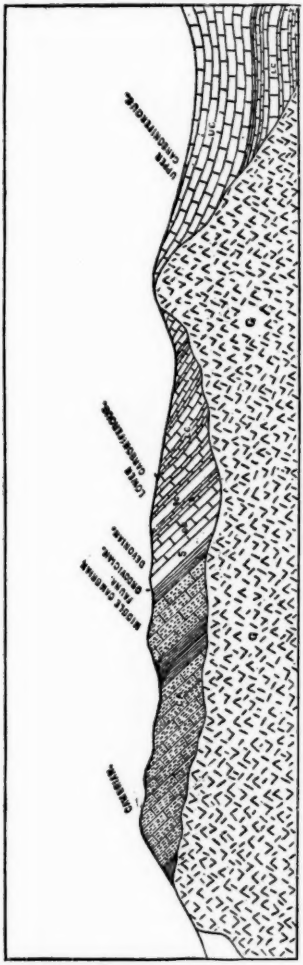


Fig. 2.—Wasatch section. This crosses the Wasatch Mountains a little south of Big Cottonwood Cañon. Copied from map of sections accompanying vol. i, Geol. Expl. of Fortieth Parallel. Scale, about 10,000 feet to the inch. The Cambrian strata are represented as resting unconformably on the granite and as overlaid by the conformable Lower Silurian (Ordovician) strata. The position of the Middle Cambrian fauna is indicated just below the Silurian horizon. CA, Cambrian; S, Silurian; OD, Devonian; LC, Lower Carboniferous; UC, Upper Carboniferous; G, Granite. Further study in the field will probably result in a somewhat different representation of this section, as it was originally based on rapid reconnaisance work by the geologists of the Fortieth Parallel Survey. The relations between the granite and the overlying strata are not as understood by myself, but are given as in the original section.

Fortieth Parallel Survey (Geol. Expl. 40th Par., vol. i, p. 229; vol. ii, p. 366), but I had the opportunity of examining it more in detail during the summer of 1885, and through finding the

Olenellus or Middle Cambrian fauna, located its upper horizon and ascertained that the entire Upper Cambrian was absent by non-deposition, the Silurian resting conformably on strata of Middle Cambrian age. The section at the base rests on granite near

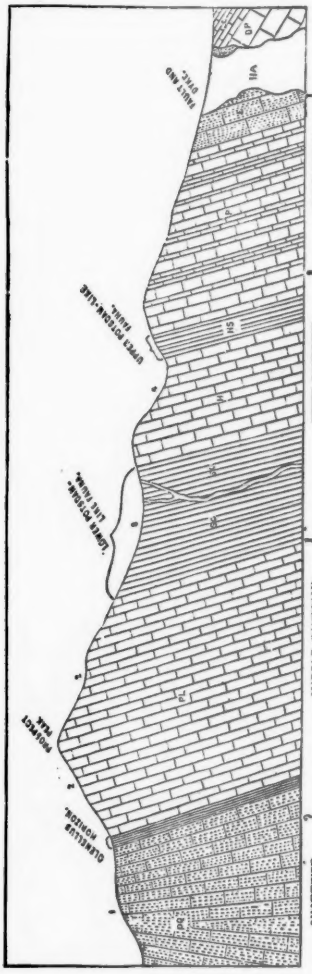


Fig. 3.—Eureka section. This extends over the Cambrian strata of the Eureka district and up to the base of the Trenton limestone horizon of the Lower Silurian (Ordovician). The numbers on the upper line correspond to the numbers on the divisions given in the descriptive section: 1 and PQ, Prospect Mountain quartzite; 2 and PL, Prospect limestone; 3 and SC, Secret Cañon shale; 4 and H, Hamburg limestone; HS, Hamburg shale; P, Pogonip limestone; E, Eureka quartzite; HA, hornblende-andesite; LC, Lower Carboniferous; DP, Devonian. The dike represented in the Secret Cañon shale is not continuous, and on the line upon which the fossils were collected it was not observed, the section being unbroken from 1 to the great dike beyond the Eureka quartzite. The section is copied from the unpublished map of sections, by Mr. Arnold Hague, illustrating the Geology of the Eureka district. Scale, 1,800 feet to the inch.

the mouth of Big Cottonwood Cañon, and the strata continue up the cañon in an unbroken, conformable series of siliceous rock, shales, quartzites and sandstones, until 12,000 feet in thickness

is passed through. In the upper 250 feet of silico-argillaceous shales that rest on a massive band of quartzite, 3,000 feet in thickness, the following fossils occur: *Cruziana?*, *Lingulella Ella*, *Kutorgina pannula*, *Hyolithes Billingsi*, *Leperditia Argenta*, *Olenellus Gilberti*, *Ptychoparia quadrans* and *Bathyuriscus producta*. This fauna is also found at a similar horizon in several localities in Nevada; and the lithologic, stratigraphic and paleontologic evidence, as found in the Oquirrh and Tintic ranges of Utah and the House, Eureka and Highland ranges of Central Nevada, extends the same horizons throughout the western and southern portions of the Great Basin area.

The entire absence of fossils in the lower portions of the Wasatch section may be owing to the character of the sediments; but an attempt is made further, to explain the absence of the Lower Cambrian fauna of the Atlantic area.

The second section (fig. 3), that of the Eureka District, by Mr. Arnold Hague, stratigraphically overlaps that of the Wasatch, the lower 1,500 feet of quartzite corresponding to the upper-half of the 3,000 feet of quartzite of the Wasatch section, and the Olenellus shales occurring at the same horizon on the summit of the quartzite; but here the Lower Silurian (Ordovician) strata do not rest on the siliceous Olenellus-bearing shales, but are separated by over 6,000 feet of limestone that carries a fauna uniting the Middle Cambrian fauna with the Upper Cambrian or Potsdam fauna, which begins in its characteristic forms 4,500 feet above the Olenellus horizon. One hundred miles south of Eureka, in the Highland Range, I found the Eureka section essentially repeated and identical species occurring at the same relative horizons in each section. The vertical range of the Eureka section embraces the corresponding strata of the Highland Range section and several sections that occur in Nevada and Western Utah.

Section No. 3, fig. 4, is unlike either of the first two sections in having the Upper Cambrian well developed, and the Middle, and probably the Lower Silurian (Ordovician), entirely absent. This section is beautifully exposed in the deeper portions of the Grand Cañon of the Colorado, Arizona, and was first made known in a general way, through the explorations of Major J. W. Powell in 1875. During the winter of 1882–83, Major Powell instructed me to make a detailed section of the strata in the depths of the cañon, and fig. 4 is one of the results of the work. The Upper Cambrian, or Tonto formation is 1,000 feet in thickness, composed of siliceous and calcareous strata and carries a fauna that unites it closely with that of the Upper Cambrian of Nevada, Texas and the Upper Mississippi Valley. Beneath the Tonto there is a great mass of strata, over 12,000 feet in thickness, that are unconformable to the horizontal Tonto

strata above and the highly-inclined (Huronian?) strata beneath. I have heretofore referred the pre-Tonto series to the Cambrian and correlated it with the Keweenaw of Wisconsin and Llano series of Texas, but I am now inclined to call all these series

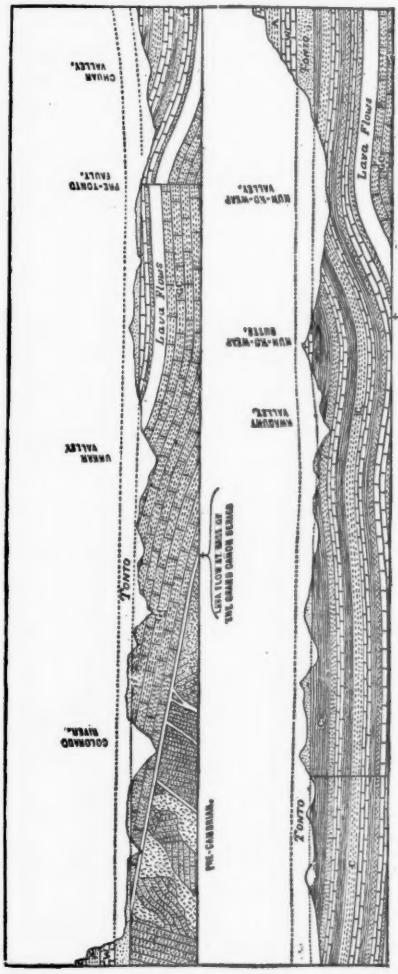


Fig. 4.—Grand Cañon section. The section represented by this figure crosses the pre-Tonto strata nearly at right angles to their strike as exposed in the Grand Cañon of Colorado, Arizona, and studied by the writer. Horizontal scale, 12,500 feet to the inch. Vertical scale about 8,500 feet to the inch. The Upper Cambrian (Tonto formation) has been removed by erosion on the direct line of the section, but is present, as indicated by the dotted lines, around the margins of all the cañons that cut it on the line of the section. GC, Grand Cañon formation (the lava flows also belong to this); T, Tonto formation; W, Red Wall Carboniferous limestone; A, Aubry Carboniferous sandstone (above this comes the Aubry Carboniferous limestone, which forms the outer wall of the cañon). All the strata beneath the Tonto formation are considered as pre-Cambrian.

pre-Cambrian and a system of equal degree with the Cambrian, Lower Silurian (Ordovician), etc. If this is done the strata below the Grand Cañon series will be correlated with the Huronian of the Wisconsin section. This will be referred to again.

The Grand Cañon section is typical and includes with it the Cambrian section of Central Texas and Northern Wisconsin (see figures 5, 6).

Crossing to the eastern side of the Continent, our next section (fig. 7, p. 148) of the Cambrian strata is taken in Northwestern Vermont, and its contained faunas serve to connect the distant Nevada sections and the group of Cambrian sections along the St. Lawrence, Champlain, and Hudson River Valleys.

At the base of the section a massive belt of limestone, 1,000 feet in thickness, carries in its upper portions the Olenellus fauna which, in the argillaceous shales capping the limestones, attains an extensive development. Continuing up in the section through the argillaceous shales, about 2,000 feet, masses

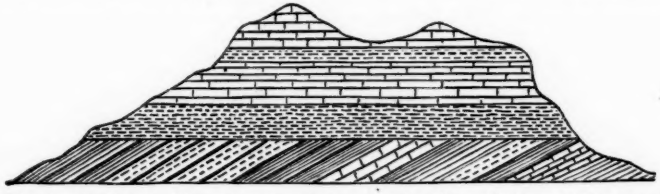


Fig. 5.—Section in Llano County, Texas, showing the relations of the Upper Cambrian (Potsdam) and the pre-Cambrian Llano Series.

of limestones are found interbedded in the shales, and in the limestone fossils that show the near approach of the Upper Cambrian or Potsdam fauna. The section gives the same succession of fauna as the sections of Nevada, where we find positive stratigraphic proof of the great difference in age of the Middle and Upper Cambrian faunas.

The Georgia, Vermont, section includes, in its vertical range, the sections about and below Troy, N. Y., in the Hudson River Valley, and those of Northwestern Newfoundland and the Straits of Belle Isle.

Directly east of the Adirondack Mountains of New York, the Potsdam sandstone is overlaid by a stratum of shaly arenaceous rock full of fucoidal, or annelid markings, and there the Chazy limestones appear resting on the latter.* Tracing the sandstones south, a fine exposure is seen at Ausable Chasm, and continuing south a limestone is found coming in on top of the sandstone that, in Saratoga County, contains a well-marked fauna of twelve species, four of which are identical with species in the upper beds of the Wisconsin Potsdam sandstone. The calcareous layers of the Potsdam also occur at Whitehall, and Professor Dwight has found them near Poughkeepsie.

* The unconformity, by non-deposition, noticed by Sir William Logan, is nowhere better illustrated than at this point, the Calciferous formation being absent from the section.

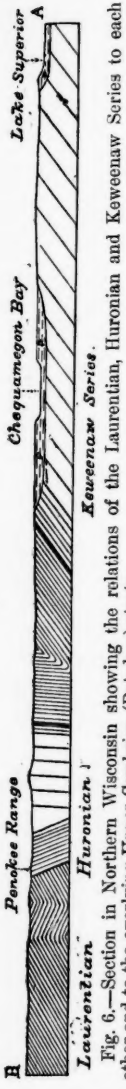


Fig. 6.—Section in Northern Wisconsin showing the relations of the Laurentian, Huronian and Keweenaw Series to each other and to the overlying Upper Cambrian (Potsdam) strata.

During the deposition of the Potsdam sandstone the shore-line was close at hand, and the Adirondack area furnished material for the formation. Out from the shore-line the mud and sand were mixed, and still farther out, over the present area of the Georgia section, the shales with interbedded limestones point to deeper, quieter waters. I have yet failed to find in Vermont any Potsdam sandstone north of Burlington; and the evidence goes to prove that the upper portion of the Georgia section, with its shales and "lentiles" of limestone, is equivalent to the Potsdam sandstone about the Adirondacks.

We have now hastily reviewed the principal sections of the Cambrian under which all the others now known can be grouped except those of Braintree, Massachusetts, St. John, New Brunswick and the southeastern Newfoundland sections. These are not connected paleontologically with the more western section and we distinguish them as the Atlantic border sections, and mostly of older date* than the strata of all but the lower portions of the Wasatch, and perhaps the Tennessee sections. As the position of the Atlantic border Paradoxides fauna is determined on paleontologic evidence, the discussion of it will be taken up later.

In the following table, the writer expresses his view of the classification of the various formations that go to make up the Cambrian system of North America. It is subject to revision in details, but the main divisions are based on paleontologic and stratigraphic data, that I think will render them of service in the permanent classification of American Paleozoic rocks.

It is not claimed that the arrangement of the formations in the following table is original with me, as, with some changes in nomenclature, it is the same as that to be found on page 46 of the Report of the Geological

* At St. John, New Brunswick and also in Newfoundland, the higher members of the Cambrian system, containing the later Cambrian faunas are known, but, with our present information, the lower fauna predominates, and the upper faunas will probably prove to be more closely related to the Atlantic than to the interior basin, although we may expect to find a number of species common to each.

Classification of North American Cambrian Rocks.

UPPER CAMBRIAN.	Lower Calciferous.	Lower portion of the Calciferous formation of New York and Canada. Lower Magnesian of Wisconsin, Missouri, etc.
	Potsdam, Knox, Tonto.	Potsdam of New York, Canada, Wisconsin, Texas, Wyoming, Montana and Nevada: Tonto of Arizona; Knox Shales of Tennessee, Georgia and Alabama. The Alabama section may extend down into the Middle Cambrian.
MIDDLE CAMBRIAN.	Georgia.	Georgia formation of Vermont, Canada and New York.
	L'Anse au Loup.	Limestones of L'Anse au Loup, Labrador.
	Prospect.	Lower part of Cambrian section of Eureka, and Highland Range, Nevada. Upper portion of Wasatch Cambrian section, Utah.
LOWER CAMBRIAN.	St. John, Braintree, Newfoundland, Wasatch. Tennessee.	Paradoxides beds of Braintree, Mass., St. John, New Brunswick, St. John's area of Newfoundland, Lower portion of Wasatch section, Utah. The Ocoee conglomerate and slates of East Tennessee are doubtfully included.

Survey of Newfoundland for 1865, published in 1866, by Sir William Logan, and based largely on the paleontological work of Mr. E. Billings.

Fauna of the Cambrian System.

As has long been well known, the Trilobita form by far the largest portion of the Cambrian fauna. Of the ninety-two genera and three hundred and ninety-three species known to me at present from the American Cambrian, 31 genera and 226 species are placed under the Trilobita, and 61 genera and 167 species under all the other classes. The Brachiopoda come next with 15 genera and 67 species; Crustacea with 10 genera and 15 species, etc.

In the accompanying table a summary is given of the Cambrian faunas of North America, as far as known to me, up to the present date. A critical study of the Upper Cambrian faunas will eliminate some of the genera and species and, also, add others. The study of the Lower Cambrian fauna of New Brunswick is now being carried forward by Mr. G. F. Matthew, and that of the Upper Cambrian by myself; and probably within two years the Cambrian fauna of North America will include more than 100 genera and 400 species, as to-day there are 92 genera and 393 species published, that I have included in the fauna. There are a number of genera and species not included that do not appear to be based on organic remains, or are synonyms of some of those that are included.

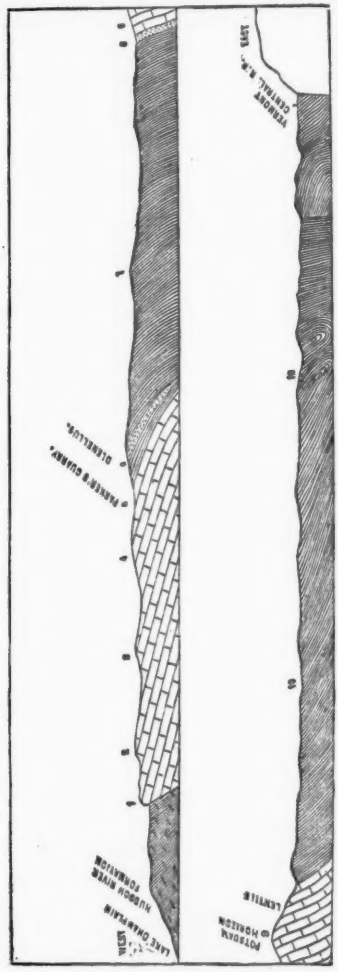


Fig. 7.—Georgia section. This extends from Lake Champlain east to the Vermont Central Railroad track, and passes through the Parker trilobite quarry, and a little south of the town of Georgia post office. Horizontal scale, about 2,000 feet to the inch.
The figs. 1 to 10 indicate the position of the lower strata of each of the divisions given in the descriptive section.

Geologic Résumé.

	Genera.	Species
Upper Cambrian	52	213
Middle Cambrian	43	107
Lower Cambrian	32	76
	127	396
Reappearances	35	3
Total fauna	92	393

Zoologic Résumé.

	Genera.	Species.
Algæ	3	9
Spongiæ	6	13
Hydrozoa	4	5
Crinoidea	1	3
Annelida	2	5
Brachiopoda	15	67
Lamellibranchiata	1	1
Gasteropoda	14	29
Pteropoda	5	20
Crustacea	10	15
Pœcilopoda	31	226
	92	393

There are 14 genera common to the Lower and Middle Cambrian; 15 common to the Middle and Upper Cambrian; 11 common to the Lower, Middle and Upper Cambrian, and 12 common to the Lower and Upper Cambrian.

Of the 52 genera in the Upper Cambrian, 17 are much more strongly represented in the second fauna, viz: Lingula, Orthis, Leptæna, Triplesia, Bellerophon, Euomphalus, Holopea, Maclurea, Metoptoma, Ophileta, Pleurotomaria, Hyolithes, Serpulites, Amphion, Bathyurus, and Ogygia.

Of the above genera, Discina, Pleurotomaria, Amphion, Bathyurus and Ogygia are doubtfully referred to the Cambrian. Several other genera pass up into the base of the Lower Silurian (Ordovician), but are not considered as at all characteristic of its fauna.

When an accurate stratigraphic and paleontologic study is made of the passage beds between the Cambrian and Lower Silurian (Ordovician) systems, or the Potsdam and Upper Calciferous formations of the New York and Canadian sections, we shall possess the data upon which to compare the faunas of the two systems. At present it is to a large extent wanting.

Stratigraphic position of the Upper, Middle and Lower Cambrian Faunas.—That the stratigraphic position of the Middle Cambrian fauna on the North American continent is below that of the Potsdam fauna is shown by the Eureka and Highland Range sections, in Nevada, and the Georgia section, in Vermont. In Nevada, in two sections unbroken by faulting or folding of the strata and separated by a geographic distance of one hundred and twenty-five miles, the fauna ranges from 2,000 to 4,000 feet below strata carrying a typical Upper Cambrian, or Potsdam fauna. But three species, *Protospongia fenestrata*, *Acrotreta gemma* and *Stenotheca elongata* are known to pass up to the Upper Cambrian or Potsdam horizon. In the Georgia, Vermont, section, one of the species, *Ptychoparia*

Adamsi appears to pass up into the Potsdam horizon of the section, where the fauna is more like that of the Potsdam; and of the other species, *Orthisina Orientalis* is much like *O. Pepina* of the Potsdam sandstone of Wisconsin; but the fauna, as a whole, is so clearly distinct from the typical Potsdam of New York, Wisconsin, Tennessee, Alabama, Texas, Arizona, Nevada and Montana that, even without any section to show their relations to each other, I should not think of correlating them as contemporaneous faunas.

The stratigraphic relations of the Middle Cambrian fauna to the Paradoxides fauna of St. John, Braintree and Newfoundland are not so clearly proven as for the Middle, and Upper Cambrian faunas. The only locality known where the two faunas are in the same geographic area is about Conception Bay, Newfoundland. At Topsail Head about 100 feet of limestone is exposed, overlaid by dark shale. All stratigraphic connection with other sections in the vicinity is broken. The fossils in the limestone are not numerous, but Mr. Billings pronounced them Potsdam (Geol. Newfoundland, p. 158, reprint of report for 1868), and identified *Salterella*, *Crania* (probably *Kutorgina*) *Labradorica*, and I found, in the collection of the Geological Survey of Canada, *Scenella reticulata*, *Stenotheca rugosa*, *Iphidea bella* and *Protypus senectus* var. *parvulus*, which gives six species that are also known from the Middle Cambrian horizon of L'Anse au Loup.* Special stress is placed by the writer on the occurrence of these fossils at Topsail Head, as it is in the midst of the Paradoxides basin. Mr. Alexander Murray correlated the Topsail Head limestone with that of other localities, and places it beneath the Paradoxides-bearing shales of St. Mary's Bay (on the page cited above), but without paleontologic or stratigraphic evidence that can authorize him to say more than that a supposed connection is indicated.

Not having stratigraphic evidence of the relation of the Georgia or Middle Cambrian fauna and the Paradoxides or Lower Cambrian (Ordovician) fauna other than that they occur in the same area and are not in the same stratum of rock, we turn to the faunas to aid us in the settlement of the question.

Of the thirty-two genera of the American Paradoxides horizon, fifteen pass up into the Olenellus horizon, viz: Arenicolites, Protospongia, Archæocyathus?, Eocystites??, Lingulella, Acrotreta, Acrothele, Kutorgina, Orthis, Stenotheca, Hyolithes, Agnostus, Microdiscus, Solenopleura, and Ptychoparia. Of these, eleven, Arenicolites, Protospongia, Lingulella, Kutorgina, Acrotreta, Orthis, Hyolithes, Stenotheca, Agnostus, Microdiscus? and Ptychoparia, continue on up into the Potsdam or

* Mr. Billings called all the Middle Cambrian fauna "Lower Potsdam," which explains his referring the Topsail Head fossils to the Potsdam.

Upper Cambrian horizon, leaving but four genera that are alone common to the Middle and Lower horizons. One genus, Dendrograptus, is doubtfully identified in the Paradoxides horizon of New Brunswick that occurs in the Upper Cambrian, and is, as yet, unknown in the Middle Cambrian. The genus Agraulos is also found in the Lower and Upper, but not in the Middle Cambrian. Of species, not one of the 76 of the American Lower Cambrian fauna are known to occur in the Middle Cambrian fauna, which, with its 107 species, stands out clearly from the older fauna and also from the more recent Potsdam fauna, as but three of its species, *Protospongia fenestrata*, *Stenotheca elongata* and *Acrotreta gemma*, are known to occur in the Upper Cambrian, and 16 of the genera in the Middle Cambrian are not known to pass up into the Upper Cambrian or into the Lower Silurian (Ordovician) faunas. Not one species is known to be common to the *Lower* and *Upper* Cambrian horizons.

Having studied the Middle Cambrian fauna more thoroughly than that of the lower and upper horizons, I will speak of it on that account and, also, from the fact that its character and geographic distribution is not as well known as the other two.

As a whole, we notice that it combines the characters of the Lower Cambrian and Upper Cambrian faunas and yet is distinct from each of them. There does not appear to be an equivalent fauna in the Cambrian system of Europe either in Bohemia, the Scandinavian area, or in Wales; but from the Island of Sardinia, Dr. Bornemann has described a group of sponge-like bodies closely related, if not identical with *Ethmophyllum* and *Archæocyathus* of the American Middle Cambrian fauna; he also names *Kutorgina cingulata* which is found at this horizon both in Vermont and Labrador. A species of trilobite is referred to Olenellus, but I have not seen any illustration of it.

The conditions that developed the Middle Cambrian fauna appear to have been largely peculiar to the American continent. During the deposition of the St. John's series of the Lower Cambrian, or the Paradoxides strata, we learn from the European and Eastern American sections, that the fauna was essentially of the same type over the entire basin (Atlantic), and, from evidence known to date, that the fauna did not extend west of a line passing northeast through Eastern Massachusetts to New Brunswick and Newfoundland.

That there were deposits of sediment to preserve the fauna, if it extended westward, is shown by the thousands of feet of sediments below the Middle Cambrian faunas of Utah and Nevada.

From the data we now have, I think that during the exist-

ence of the greater portion of the Lower Cambrian (Paradoxides) fauna, a barrier existed that prevented its extension westward of the line mentioned; that towards the close of the time of the Paradoxides fauna that barrier was removed to the northeast, in the vicinity of Newfoundland, and the descendants from the Paradoxides fauna entered the westward seas and spread to the eastern and western basins and formed the Middle Cambrian fauna. What route was taken by the Middle Cambrian fauna after passing to the western side of the outer barrier is not yet traced, but I think from the indications we now have of a continental area, during Lower and Middle Cambrian time, in the central portion of the continent, that the fauna passed to the south around the southern end of the then existing land, and thence north along the west shore. In the Atlantic basin, the Paradoxides fauna persisted to a greater or less extent and mingled with the types of the Upper Cambrian fauna as in the Upper Lingula Flags of Wales.

If this is a correct interpretation of the evidence now known, we may look in vain in the central interior basin for the Paradoxides fauna of the Atlantic basin.

That there was life in the older Cambrian or pre-Cambrian seas of the central interior basin, there is no doubt, as we have found traces of it in the Grand Cañon section of Arizona; and the development of that fauna which from the stratigraphy is pre-Cambrian, is one of the problems awaiting solution.

During the Upper Cambrian (Potsdam of America; Upper Lingula Flags of Wales), the Atlantic and Pacific basins appear to have had free communication with each other, and the faunas now have a facies of the same general character.

The above views are, to a certain extent, theoretical, but the facts demand an explanation other than that the faunas of the Lower, Middle and Upper Cambrian were contemporaneous but in different geographic areas. That the upper and middle faunas were separated by a great interval, is shown by the sections in Nevada and Vermont; and that the middle and lower faunas were not contemporaneous is shown by the biologic evidence and the indirect evidence of the absence of the lower fauna in association with the middle fauna in the Newfoundland area, where they are now found in different strata, but a short distance from each other.

A diagram illustrating the Cambrian sections of America and Europe would show, in the former, that the sequence of life is divided more sharply into three great groups that, in the latter, are more or less broken up. First: by the nearly entire absence of the middle group, and secondly, by the commingling of the upper and lower groups in the European strata and possibly in the Atlantic border sections of New Brunswick and

Newfoundland. This subject will be treated in detail after the completion of the study of the Upper Cambrian faunas now in progress.

As previously mentioned, I have heretofore included the Grand Cañon and Llano series as, in part, of Cambrian age, and correlated them with the Keweenaw series (Bull. VI, Phil. Soc. Washington, p. 102, 1882). In adopting the view that all of these may be placed under a system of pre-Cambrian age, I think there is good reason for it in the presence of the great unconformity, by erosion, between the strata of the Keweenaw system* and the known Cambrian formations. An examination of the sections shows that in each of them there is a great series of disturbed and eroded strata overlaid by the horizontal beds of the Upper Cambrian; and in the Keweenaw, and the Grand Cañon sections, this great series of strata is in turn separated from the formation below by an unconformity that, in the Grand Cañon, is very great, and in the Lake Superior area, sufficient to indicate an orographic movement previous to the deposition of the Keweenaw strata. All three of the sections (figs. 4, 5, 6) agree in the evidence of an extended orographic movement and a great period of erosion at the close of deposition of the Keweenaw series; and I am now of the opinion that the Keweenaw system should be considered as pre-Cambrian. The correspondence in the position of the pre-Grand Cañon strata, separated from the Grand Cañon series by a great unconformity, to the Huronian as described by Irving, is so striking that more than calling attention to it is unnecessary.

The presence of organic remains does not necessarily imply that the strata are of Cambrian age except they show a marked Cambrian facies; and unless this is the case I should not contend for a moment against well-proved stratigraphic evidence of greater age and marked structural breaks in the stratigraphic succession. It may be asking too much for the period of erosion, between the Keweenaw system and the Upper Cambrian, to say that 12,000 feet of mechanical sediments and 4,000 feet of limestone accumulated in the Utah-Nevada basin while this erosion was taking place; but, if we look higher up in the Grand Cañon section, and that of Central Nevada, we find that 200 feet of Silurian and Devonian strata in the former is repre-

* The Keweenaw system is here used to include the Keweenaw series of the Lake Superior region, the Llano series of Texas and the Chuar and Grand Cañon series of the Grand Cañon of the Colorado, Arizona, and is considered as of equal value with the Cambrian, Lower Silurian (Ordovician), Upper Silurian and other systems of the Paleozoic Group, and as belonging to the Paleozoic rather than to the Archean. It may be that the Keweenaw and Grand Cañon series belong to distinct systems of strata, but until this is proven I prefer to provisionally refer them to a pre-Cambrian post-Huronian system. I think the Grand Cañon and Llano strata belong to one system.

sentative of the 13,000 feet of limestone of the same formations in Nevada, and no unconformity, by any extensive erosion, is indicated; and, again, the 9,000 feet of limestone of the Upper Cambrian and Lower Silurian (Ordovician) of the Central Nevada section is unrepresented in the Wasatch section of Utah. These facts readily prepare us to believe that the hiatus between the Keweenaw and Upper Cambrian is fully equivalent to the period of the Lower and Middle Cambrian.

Another reason is that from the extended orographic movement preceding the erosion of the Cambrian, we should expect to find evidence of that erosion in the Cambrian of Utah and Nevada, but, as yet, none such is known.

Thus far the question of the existence of the Keweenaw system has been treated from a purely structural basis,* but, in the course of my study of the distribution of the Cambrian faunas, I have met with some facts that require an explanation and the most plausible one demands the existence of an extended orographic movement, prior to the deposition of the Cambrian strata of the western side of the Continent, that raised a land area over the central portion of the Continent which existed up to the period of the beginning of the deposition of the Upper Cambrian formations, when it was depressed beneath the level of the sea and the Upper Cambrian strata deposited over portions of it.

The facts demanding explanation are: 1st. The entire absence, as far as known to date, of the Lower Cambrian or Paradoxides fauna west of the Atlantic border: 2d. The absence of the Middle Cambrian or Olenellus fauna over areas occupied by the formations of the Keweenaw system.

If we accept the view that the Keweenaw, Grand Cañon, and Llano strata are outcrops of a system of strata of pre-Cambrian age that extended, in connection with the Huronian and Laurentian beneath it and projecting up through it, from the great body of Archean land on the north, southward over the area now occupied by the central portions of the Continent, or the Mississippi Valley, and westward to the area occupied by sediments accumulated on the western side of the Keweenaw system of strata when the latter formed a land area, then the explanation asked is given. The pre-Keweenaw portion of this Keweenaw land must have been extensive as, in the Missouri area at St. Louis and the Ozark Mountains, the Archean appears beneath the Upper Cambrian; and all the eastern slopes

* Professor T. C. Chamberlain gives a most excellent summary of the Keweenaw series and its stratigraphic position in vol. i, of the Geology of Wisconsin. In the section, on page 65, it is placed as a distinct system, resting unconformably on the Huronian which, in turn, is separated from the Laurentian by an unconformity. The Cambrian is shown above the Keweenaw as a system between it and the Lower Silurian (Ordovician).

of the Rocky Mountains of Colorado show only the thin Upper Cambrian formations resting on the Archean; and the same is true in the Black Hills and in Central Wyoming. The

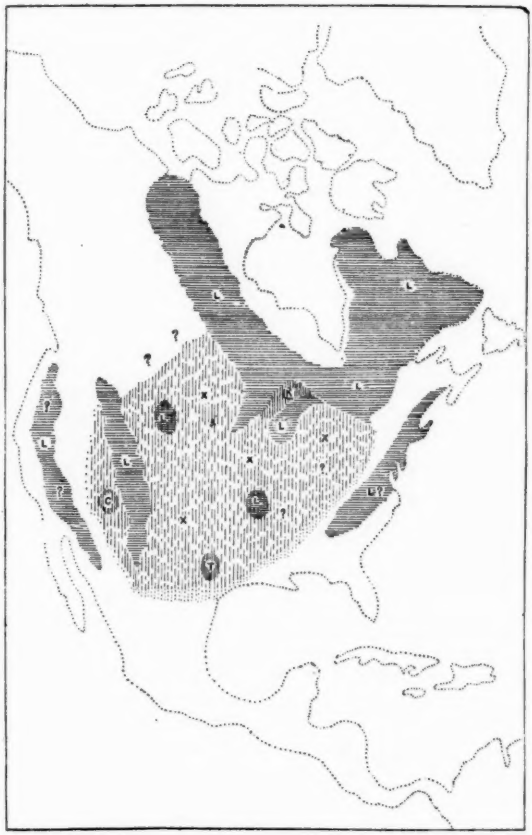


Fig. 8.—Hypothetical map showing the supposed Keweenaw land or continent as it existed just before the deposition of the Upper Cambrian (Potsdam) sediments. The latter probably extended over most of the area marked X, X, X, although now concealed by the later sedimentary deposits. The age of the eastern and western belts, marked L?, is still in doubt, but the presence of the eastern belt is strongly indicated by the geographical distribution of the Cambrian faunas. L, Laurentian and other Archean formations; K, Keweenaw; T, Llano formation; C, Grand Cañon formation; X, X, X, area supposed to have been land surface but now concealed by later deposits.

existence of these Archean areas with the Upper Cambrian deposits proves the early date of their elevation, and that they

were the shore line of the pre-Cambrian Keweenaw sea. What the eastern boundaries of this sea were, we do not now know, but the inference, from what is known of the Archean of the Appalachian system, is that portions of the latter were above the ocean during the deposition of the Keweenaw system.

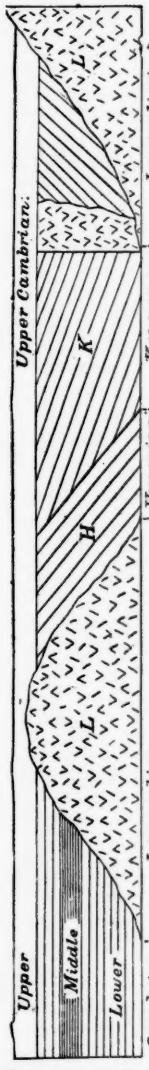


Fig. 9.—Ideal section to show the relations of the Upper Cambrian (Potsdam) strata to the old Keweenaw land. The Middle and Lower Cambrian strata are shown resting against the slope of the old Keweenaw continent, and the Upper Cambrian extending over it. The section is diagramatic, but may give the views of the writer to the reader more clearly than the description in the text.

The traces we now have of this Keweenaw land point to its extension from the Lake Superior region south to Central Texas and westward to Central Northern Arizona. A glance at the map (fig. 8) shows how far apart the relatively small exposures are; but, the great similarity of the sections and their position in relation to the Upper Cambrian that rests on the eroded surface of each visible area, points to a wide spread orographic movement that raised the entire central portion of the Continent and again depressed it at the termination of the period of erosion preceding the deposition of the Upper Cambrian or Potsdam sediments of the Upper Mississippi Valley, Central Texas and Arizona.

The existence of such a land over the area mentioned, is shown by the sections we now know; and I think that, when the areas of Cambrian and Archean rocks in Missouri and also along the Southern Appalachian chain come to be studied with the view that such a land existed during the period of the deposition of the earlier deposits of the Cambrian system, evidence will be forthcoming to show its former presence over a large area. On the north it probably joined the Archean continent and thus gave a greater extension of the pre-Cambrian continent to the south that, during the early history of the Cambrian period, furished more or less of the sediments of the strata of the Lower and Middle Cambrian. The Archean boundaries of the Keweenaw sea continued after the elevation

of the Keweenaw land. When Keweenaw land is spoken of, I refer to that formed of the strata of the Keweenaw system and the Archean rocks with which it was associated.

Before the Keweenaw land was depressed the Middle Cambrian fauna passed through or around the barriers between the Atlantic and western seas, and, as the Keweenaw land was disappearing beneath the waters, the Upper Cambrian fauna spread over the area occupied by it and left its record to aid us in fixing the geologic date of the submergence of the Keweenaw land and to explain the absence of the Paradoxides or Atlantic fauna in the early Cambrian strata of the western side of the Continent. In the diagramatic section (fig. 9), I have endeavored to show the relations of the Potsdam or Upper Cambrian to the Keweenaw land.

The evidence of the existence of the Keweenaw land is both stratigraphic and paleontologic. That life existed in the seas at the time of the deposition of the sediments of the Keweenaw system, is shown by its presence in the Chuar formation of the Grand Cañon series.

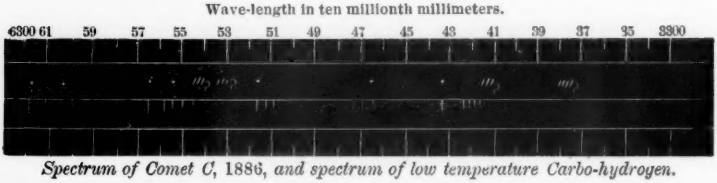
It may be urged that there is too much theorizing, on insufficient data, in the preceding statements, but, while waiting the accumulation of evidence it is well to have a working theory and as such the "pre-Cambrian Keweenaw land" is proposed, and the fragmentary remains, less the Archean portions, called a "pre-Cambrian Paleozoic System."

Art. XVII.—*Note on the Spectrum of Comet C*, 1886; by O. T. Sherman.

Comet C, 1886, presents to telescopic view, a faint oval of light about one and a half minutes in diameter. In the north proceeding quarter is a poorly defined condensation. Although well situated for observation, it is yet not especially suited for spectroscopic analysis; still out of curiosity the equatorial of the Yale Observatory was turned thereon. The result is not without interest: no less than seven loci of light present themselves, where three are usually seen.

On account of the circumstances it is necessary to describe somewhat in detail the apparatus and mode of observation. The comet's light focused upon the plane of the slit by the object glass of the equatorial (8 in.), and passing through the collimating lens falls upon a Rowland's flat grating, 14,347 lines to the inch, and is then focused for observation by a small telescope with low power eye-piece. The grating is fastened to an arc moved by a tangent screw, allowing the

successive spectra to be observed as far as the D line in the fourth spectrum. The screw carries a rider bearing a double recording apparatus. The instrument being then pointed to the star, the observer brings portion after portion of the spectrum before the eye-piece. When he is fully convinced that a patch of light is before him, it is brought up to a thick cross wire, an automatic record made and the screw again turned till the observer is again convinced that an image of the comet is before him. Throughout the whole operation no light other than that of the comet was admitted. The information to be gained from the color of the image is, for faint light, very slight, and save such information, the observer's whole knowledge of his work is bounded by the fact that he started from a certain spectrum-place and will be stopped when he reaches a certain spectrum-place. Datum lines afforded by salted alcohol flame or Plücker tube, are finally added to the record. The record being withdrawn the observer has before him a double series of positions. By means of the datum lines these are converted into wave-lengths. If the same line is found in four out of six spectra it is set down as observed, if less than four, it is classed as suspected. If observed on every day of observation the reality of the line is accepted, if missed on some occasions it is only suspected. The faintness of the comet's light renders these precautions necessary.



Spectrum of Comet C, 1886, *and spectrum of low temperature Carbo-hydrogen.*

To such a process the spectrum in question was subjected on May 26, 28, and June 4. The operation was repeated through the first, second, and third spectra, and again through the third, second, and first. The resulting loci have the following approximate wave-lengths: 618·4, 600·6, 567·6, 553·7, 517·1, 468·3, 433·2, with strongly suspected loci at 545·4, 535·0, 412·9, and 378·6. These positions may be in error by one or two units. It is of interest to compare them with the following, given by Hasselberg* as the chief lines of the Hydrocarbon spectrum: 618·7, 599·7, 563·4, 553·9, 5472, 516·4 469·7, 431·1. Of these loci 553·7, 517·1, 468·3, may well be the bands common in cometary spectra; 567·6 not uncommon, while 618·4 and 433·2 are probably those suspected by at least two

* Ueber Die Spectra der Cometer Dr. B. Hasselberg, p. 21.

observers in comets B and C, 1881,* and by Secchi† in comet 1111, 1874. In carbon spectra and comet spectra also bands in the violet and ultra violet 414–420, 385–389, are photographed.

The comparison of this spectrum with the low temperature spectrum of carbo-hydrogen‡ is not without interest. The distance of the comet from the sun was greater than 1·5. It may perhaps be suggested that the difference between this spectrum and that usually observed is due to temperature. It would be well if we had for the carbon compounds, a chart at successive heat levels, after the manner of that drawn up by Lockyer§ for the photographed spectra of some carbon compounds.

SCIENTIFIC INTELLIGENCE.

I. Chemistry and Physics.

1. *On the Combustion of Carbon monoxide and Oxygen.*— Lothar Meyer has repeated the experiments of Dixon upon the non-inflammability of a perfectly dry mixture of carbon monoxide and oxygen, by means of the electric spark. The monoxide was prepared from magnesium formate and sulphuric acid and was shown by analysis to be pure. It was mixed with pure oxygen and in the first experiment was carefully dried for twenty-four hours with phosphoric oxide in the eudiometer. The ordinary spark of an induction coil failed to ignite the mixture; but using the primary coil of a moderately large inductorium with four large bichromate cells, ignition took place at 443^{mm} pressure. In the second experiment, the drying was continued for the same time. The mixture ignited by the spark under a pressure of 275^{mm}, but the explosion was incomplete; on increasing this pressure to 427^{mm} a second explosion took place, all the CO being burned. In the third experiment, the gas mixture was dried for six days and the sparks were continued for two minutes under a pressure of 156^{mm}. The combustion was complete. Meyer concludes therefore that carbon monoxide is not absolutely uninflammable under these conditions, but only difficultly inflammable. Moreover, since Dixon had observed an incomplete union with a series of sparks and a complete one when an ignited platinum wire was placed in the gaseous mixture, the author is of opinion that Dixon's results as well as his own are in accordance, and are all to be explained simply by difference of temperature in the spark; reduction of CO_2 to CO and O taking place when the spark is feeble, and oxidation of CO to CO_2 when it is strong.

* Monthly Notices Roy. Astr. Soc., Nov. 1881, p. 15.
† Memorie dei Spectroscopiste Ital., vol. iii, 1874, p. 118.
‡ Micrometric Gaseous Spectra. Piazzi Smyth.
§ Proceedings Royal Society, vol. xxx, p. 463.

When intermediate in strength, both actions may go on together and the gas appear to be unchanged.—*Ber. Berl. Chem. Ges.*, xix, 1099–1106, May, 1886. G. F. B.

2. *On the Combustion of Cyanogen.*—DIXON has studied the conditions under which a mixture of cyanogen and oxygen gases is exploded and has reached the conclusion that the explosion depends solely upon the nature of the spark itself. The spark from the Holtz machine failed entirely to explode dry mixtures of these gases. The induction spark failed to explode the mixture in the eudiometer where the wires were 0·25 to 1^{mm} apart; but the explosion was violent in the tubes when the wires were 1 to 3^{mm} apart, and this was quite as true when the gases were moist. He then compared the explosion rate of this mixture with that of carbon monoxide and oxygen, using for the purpose a tube ten feet long and recording the time on a pendulum-chronograph. The velocities obtained were as follows in meters per second: cyanogen and oxygen, dried with phosphoric oxide, 813, dried with KOH 808, saturated with moisture at 15°, 752. Carbon monoxide and oxygen dried with P_2O_5, 36; with H_2SO_4, 119; saturated with moisture at 10°, 175; at 35°, 244; and at 60°, 317. It is noticeable that in the latter case the explosion-rate increases rapidly when a trace of moisture is added to the mixture; while in the case of cyanogen the presence of water vapor causes a slight fall in the rate. When a platinum wire is heated in the cyanogen mixture to dull redness, the coil cooled without result when the circuit was opened. But when raised to full redness it glowed brightly for half a minute after the current was broken and orange fumes were observed in the tube. About three-fourths of the cyanogen had been converted into CO_2 and one-fourth into CO.—*J. Chem. Soc.*, xlix, 384–391, May, 1886. G. F. B.

3. *On the so-called Critical Pressure in Solids.*—V. RICHTER has discussed the phenomenon of the non-fusibility of solids under certain conditions of pressure. Lothar Meyer had shown that iodine may be fused by heat or not according to the pressure upon it. Carnelley, who studied the same phenomenon in ice, regarded the fusion as conditioned upon a certain minimum pressure, which he called the "critical pressure," and which he defined as that external pressure at which no amount of heat will fuse the solid. According to Pettersson, the critical pressure of a substance is the pressure at which the boiling point of its liquid and the melting point of the solid coincide. The author reasons that as a liquid can exist as such only when the pressure upon it is greater than the tension of its vapor at that temperature, it follows that a fusible solid under a less pressure than the vapor tension at the fusing point cannot be melted, but on heating will pass directly into the state of vapor. A solid body, then, will evaporate without fusing whenever the pressure upon it is less than the vapor tension at the fusing point. Hence he suggests that the term "fusing-point tension" is a better term than

"critical pressure," especially since the latter is already in use in another sense to indicate the pressure at the critical temperature of liquids. Whenever the fusing-point tension of a body is greater than the atmospheric pressure, the substance is fusible only by increasing the pressure upon it. This is the case with arsenic, arsenous oxide, perchlorethane and carbon dioxide. The vapor tension of CO_2 at its fusing point (−65°) is three atmospheres. Hence solid carbon dioxide, under a less pressure, cannot be melted but passes directly into the gaseous state. This explains the fact that on issuing from the containing vessel, liquid carbon dioxide becomes either solid or gaseous at once, the pressure being below that at which the liquid can exist: i. e., below the fusing-point tension. On the other hand, whenever the fusing-point tension of a substance is less than the atmospheric pressure, the phenomenon of non-fusibility can be produced only by reducing the pressure. At 0°, the tension of water and ice is $4{\cdot}6^{mm}$. Hence below this pressure, ice is not fusible. So for all substances the maximum pressure is determined by the fusing-point tension. According to Regnault, the tension of benzene at 5° (its fusing point) is $35{\cdot}6^{mm}$. Hence below this pressure, solid benzene cannot be melted even by the most rapid heating. Experiment completely confirms this prediction. On account of the less perfect vacuum required and because of its less heat of fusion, this substance is admirably suited to exhibit the phenomenon in question. A strong flask having a lateral tube by which it is connected with a water pump, contains a few cubic centimeters of benzene, in which is placed a thermometer passing through the cork. The benzene having been solidified in a freezing mixture, the flask is exhausted below $35{\cdot}6^{mm}$ of mercury and heat is applied. No fusion can be observed. The experiment is facilitated by placing between the flask and the pump a tubulated receiver cooled by ice, whereby the benzene vapor is condensed and the vacuum is maintained. On the question whether the temperature of the solid thus heated ever rises above its melting point, the author calls attention to the fact that with solids as with liquids, a definite vapor tension corresponds to a fixed temperature, each temperature having its own tension. Thus mercuric chloride, which has a fusing-point tension of 420^{mm}, has at 200° a tension of 20^{mm}; at 240°, 130^{mm}; at 265°, 250^{mm}; and at 270°, 370^{mm}. So iodine, whose fusing-point tension is 90^{mm}, has a tension of 20^{mm} at 85°, of 30^{mm} at 90°, and of 75^{mm} at 110°. Since therefore the temperature controls the tension, the fusing-point tension must be a fixed quantity and the temperature invariable. Moreover at lower pressures, solids can be heated only to temperatures corresponding to the given tensions.—*Ber. Berl. Chem. Ges.*, xix, 1057–1060, May, 1886.

G. F. B.

4. *Studies from the Laboratory of Physiological Chemistry, Sheffield Scientific School of Yale College for the Year* 1884–85. Edited by Professor R. H. CHITTENDEN. 198 pp. 8vo. New

Haven, 1885.—This large volume is an important contribution to Physiological Chemistry, and is itself the best commendation of the organization of a laboratory in which so large an amount of good work could be accomplished in a single year. The papers included are eleven in number; one of these by Professors Chittenden and H. E. Smith gives the results of a quantitative study of the diastatic action of saliva as modified by various conditions; another by the same authors shows that the absorption of arsenic by the brain is limited to cases when soluble forms of arsenic have been administered. Other papers discuss the modifications of the amylolytic action of saliva and of the diastase of malt under various conditions, also the influence of various salts and other substances upon the proteolytic action, and kindred topics.

II. Geology and Natural History.

1. *Geological Survey of Pennsylvania.* Report of the Progress of the Survey for 1885, by the State Geologist, J. P. Lesley. Harrisburg, 1886.—Professor Lesley, in this chapter from his Annual Report, reviews briefly the work of the survey since 1874, when it began. By the close of 1885, 67 volumes of reports in 8vo had been published; the survey of the counties was nearly completed, 57 large colored geological maps and two uncolored of the 67 counties had been published; an octavo hand-atlas which contains colored geological maps on a small scale of all the counties; besides several parts of the atlas of the Anthracite region and numerous detailed maps and sections in the volumes of text.

In 1885, the appropriation for the years 1885–1886 was unfortunately reduced to only $25,000 a year, one-half the previous allowance; and at the same time the legislature asked for a new survey of the oil, gas and coal fields of western Pennsylvania. This crippling of the survey in its resources when doubling on its duties was of the worst kind of economy, especially for a State whose resources are so vastly mineral and geological in nature. Still, a large amount of work was accomplished in 1885, which awaits publication.

The survey has been ably conducted, and has had, with Professor Lesley at the head, an excellent corps of geological workers. It has been pushed forward with energy and produced great and admirable results, and those engaged in it merit the confidence and thanks and generous support in whatever plans for the completion of the survey the director may present. This report is prefaced by a beautiful colored geological map of the State of Pennsylvania which in itself speaks a strong word for the survey.

2. *Volcanic Eruption in New Zealand.*—The region of the New Zealand volcanic eruption in June last (between 1 and 2 o'clock on the morning of the 10th), is northeast of the center of the broad part of the North Island near lake Tarawera. The chief seat of the eruptions was in Mt. Tarawera and its vicinity on the east

side of this lake; but great fissures were opened widely, and the small lake of Rotomahana was converted into an area of geysers and cinder craters, a dozen or more having been suddenly put into action, the geysers throwing up water and mud, and the craters steam and stones and clouds of ashes. Mt. Tarawera is known to have consisted of volcanic rocks, but not as a volcano, or as containing a crater. Its summit was a sacred place with the natives where no foreigner was permitted to intrude. The eruptions from the Mt. Tarawera region as far as reported were of stones and ashes, nothing being yet known as to ejected lavas. The ashes have buried deeply the country around, destroying the village of Waroa and others beyond recovery, and causing the death of more than a hundred persons, among whom were some English settlers. The region of the eruption is comprised within the large geyser area of New Zealand, which extended from that of Tarawera and Rotorua southwest to Mt. Tongariro. A good map of it and an account of the geysers is contained in Dr. Peale's Report on Geysers, Hayden's Geol. Survey, for 1878, and republished in 1883, at p. 313.

3. *New Minerals.*—Professor A. Weisbach has recently published a description of the interesting new mineral, called by him Argyrodite, in which the new element Germanium has been discovered (this Journal, xxxi, 308). Argyrodite crystallizes in the monoclinic system; the crystals are small and often united in rounded groups, so that they do not allow of exact measurement. The prominent planes are the prism with an angle of 115°, a clinodome ($1\text{-}\tilde{\imath} \wedge 1\text{-}\tilde{\imath} = 120°$) and a negative hemipyramid ($-1\text{-}\frac{2}{3} \wedge -1\text{-}\frac{2}{3} = 130°$); the axial relation deduced is $\dot{a} : \dot{b} : c$ (vertical) = 1 : 1·67 : 0·92. Twin crystals and drillings are common, united so that the vertical axes are inclined 112° to each other. The physical characters are: hardness = 2·5; specific gravity = 6·093—6·111; luster metallic; color steel-gray with a tinge of red on the fresh fracture, tarnishing on exposure; streak grayish black, shining; no cleavage, rather brittle. An analysis by Winkler afforded:

S	Ge	Ag	Fe	Zn
17·13	6·93	74·72	0·66	0·22 = 99·66

Argyrodite occurs as a crust upon marcasite and siderite, or again on argentite; other associated minerals are sphalerite, galena, pyrite and chalcopyrite, and also the silver minerals pyrargyrite, polybasite and stephanite. The locality is the Himmelfürst mine near Freiberg.

Arminite is another new name given by Weisbach to a hydrous sulphate of copper found on porcelain-jasper from Planitz, near Zwickau, where it has been formed in the course of the burning of a bed of coal. It forms a green coating resolved by the microscope into short needles or scales. The material analyzed was scanty and more or less impure; the analysis, regarded as the most reliable, gave Winkler:

SO_3	CuO	Fe_2O_3, Al_2O_3	CaO
24·43	56·81	0·35	0·56 = 82·15

Assuming the loss to be water, the formula $Cu_5S_2O_{11}+6H_2O$ is deduced. On the basis of some new analyses of herrengrundite, the author concludes that its true formula is $Cu_4CaS_2O_{11}+6H_2O$, or like that deduced for arminite with an atom of copper replaced by calcium.—*Jahrb. Berg-Hüttenwesen*, 1886.

4. *The Zoetrope applied to crystallographic transformations;* prepared by Professor R. H. Richards. (Milton Bradley & Co., Springfield, Mass.)—This is an ingenious and effective application of the zoetrope to the illustration of the relation between certain isometric crystalline forms, exhibiting the gradual passage of a cube into the octahedron, the dodecahedron, etc.; also similarly in the case of hemihedral forms. The beginner in the subject will be much interested and instructed by this new use of the "wheel of life."

5. *Sketch of the Flora of South Africa;* by Harry Bolus, F.L.S. Separate issue from the Official Handbook of the Cape of Good Hope. 8vo, pp. 32.—A very interesting outline sketch of the prominent features of the Botany of the Cape of Good Hope, by one to whom they are most familiar,—a district from which Linnæus was ever receiving "something new," from which the first novelties were received in Holland nearly 250 years ago, and where new species still reward the search of the diligent collector. For South Africa—that is, the portion of the continent south of the Tropic of Capricorn—is perhaps richer in number of species and of genera than any other part of the world of the same area. According to Mr. Bolus, proximate causes of this great richness "appear to be: 1, the meeting and partial union of two (perhaps three) distinct floras of widely different age and origin; 2, a highly diversified surface of the land and of the soil; 3, a climate with much sunlight (or little cloud), a condition which seems everywhere favorable to the multiplication of forms." Of the 200 phænogamous orders of the latest Genera Plantarum, South Africa reckons 142; of the 7,569 admitted genera, it has 1,255. The southwestern district, the home of the "Cape flora" proper, which has longest been known, "an angular littoral strip," of which "the greatest width does not exceed eighty miles, and probably averages not more than fifty miles," in which "the rivers are few and badly supplied with water except in winter," a country of low-growing shrubs, with hardly a tree over 25 or 30 feet high, and these only in the ravines or the mountain-sides; yet this restricted district is thought to contain 4,500 species of flowering plants. This is the home of the "cape bulbs," of 350 species of true Heaths, of a great number of "immortelles," as well as of other less notable Compositæ, of the Pelargoniums which we cultivate as "Geraniums," of Proteas and the Silver-tree, and of the so-called Calla Lily, there as abundant in all moist-lying ground as the common dock in English ditches. How unlike this flora is from any northern one, may be seen in the names and sequence of its ten largest orders, which rank as follows: Compositæ, Leguminosæ, Ericaceæ, Proteaceæ, Iridaceæ, Geraniaceæ, Gramineæ, Cyperaceæ, Restiaceæ, Liliaceæ.

A notable peculiarity of the Cape vegetation, which Mr. Bolus dwells upon, is "its power to resist the aggression of foreign invaders." Little over a dozen foreign weeds are sufficiently abundant to attract attention, and most of these only within ten miles of Cape Town, which has been a European settlement for between three and four hundred years. In this respect it is most unlike insular floras, and not very much less unlike that of Atlantic North America; the latter, however, largely on account of the operations of man in the rapid conversion of forest into cultivated fields. A. G.

6. *Descriptive Catalogue of the Gallery of Marianne North's Paintings of Plants and their Homes, Royal Gardens, Kew.* Complied by W. Botting Hemsley, A.L.S. Fourth edition, much enlarged. 1886.—Miss North's noble gift to Kew Gardens is no small addition to the attractions of that great establishment, and its scientific is not less than its popular interest. It consists, besides the accessories, of between 800 and 900 paintings of characteristic and striking plants of the principal extra-European parts of the world, temperate and tropical, made from the life and mostly in their native stations, and generally with some representation of their surroundings. That a delicate lady should have visited so many and such out-of-the-way parts of the world, alone, undergoing various privations, in order to make these paintings, is remarkable; that she should, at her own charges, build an appropriate house for them, arrange them all, as it were, with her own hand, and present the whole to the national establishment which they now adorn, is even more noteworthy. Kew Gardens and the throng of visitors indeed have "reason to be grateful for her fortitude as a traveler, her talent and industry as an artist, and her liberality and public spirit." A. G.

7. *Official Guide to the Museums of Economic Botany, Royal Gardens, Kew.*—Of this we have now the "second edition, revised and augmented," of the No. 1, *Dicotyledons and Gymnosperms*, filling 133 pages, the copious index included. It is so full of interesting matter that the still unpublished part for the *Monocotyledons* is all the more wished for. A. G.

8. *Filippo Parlatore, Flora Italiana*, continuata da Teodoro Caruel. Vol. VI, *Coralliflorœ*, p. iii.—This concluding part of the sixth volume, carries on the work from the *Scrophulariaceœ* to the *Borraginaceœ*, the latter family and the *Convolvulaceœ* making the principal bulk, although the *Gentianaceœ* are not much inferior in number of species. We note with regret a departure from general and (as we had supposed) settled usage in respect to generic names, namely, in the revival of Tournefortian names which Linnæus had superseded. For example we have *Stramonium* Tourn., instead of *Datura* Linn., *Pervinca* Tourn., instead of *Vinca* Linn. Consequently we have a set of new names, such as *Stramonium leve, S. fœtidum*, etc., in compelete contravention of all the long settled laws of nomenclature. When Linnæus established the binominal system under which Botany has flour-

ished for one hundred and thirty years, he discarded some Tournefortian names for reasons which we should now think insufficient, or, as in the case of *Datura*, he sometimes took up an earlier name. But the names which he then adopted or created were thought to be settled past recall.

The new departure which we deprecate is quite a different thing from the citation of Tournefort as the scientific founder of the genera which Linnæus adopted from him, and himself cites as Tournefortian, in which he is followed by most succeeding botanists, though not with complete regularity. A. G.

9. *Flora Brasiliensis*, fasc. xcvi, 1886, pp. 1–114, tab. 1–24, illustrates the Brazilian *Sterculiaceæ*, and is by Dr. C. SCHUMANN, one of the curators of the Berlin Royal Herbarium. A. G.

10. HOOKER'S *Icones Plantarum*, the fifteenth volume of which was completed last year, is now carried on with new vigor, we believe by means of a legacy of the late Mr. Bentham. The first part of the sixteenth volume appeared in April last, and the first part of the seventeenth followed in May. It is convenient thus to carry on the two volumes simultaneously, because one of them (the seventeenth) is devoted to Ferns, under the hand of the indefatigable Mr. Baker, the other to Phænogams. Among the latter we note with interest, plate 1514, *Asimina insularis*, Hemsley, from Corumel Island, Yucatan. In the brief account of it, no allusion is made to its affinities; so one is uncertain whether the author is aware that it is a close congener of Seemann's *Sapranthus Nicaraguensis*, enumerated in Hemsley's Botany of the Biologia Centrali-Americana. Indeed, it seems to be identical with the plant collected (flowers only) on the island of Nicaragua by Charles Wright, and mentioned in our brief monograph of *Asimina* in the Botanical Gazette for July last. Coming from Nicaragua, we took it for Seemann's species, notwithstanding the much smaller (or much less accrescent) corolla. But the fewer ovules should distinguish it, as well as the difference in size. This *Sapranthus insularis* goes to confirm the genus, which by its equal and similar, thin and plane, and equally accrescent petals, is manifestly distinct from *Asimina*. A. G.

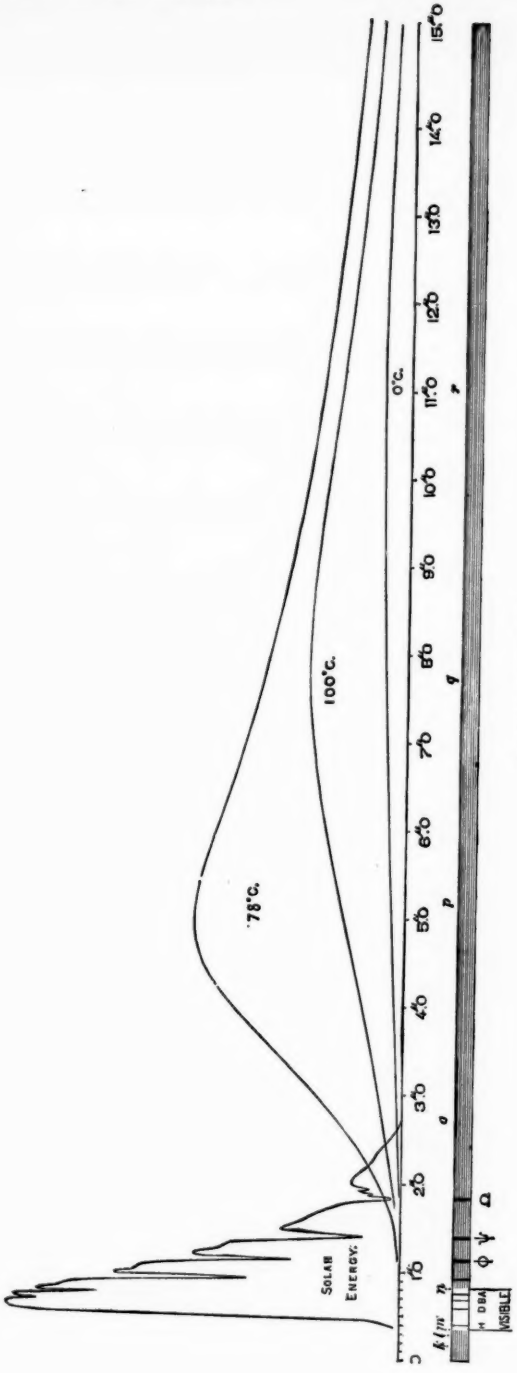
Geological Studies, or Elements of Geology, with 367 illustrations in the text, by Alexander Winchell, LL.D. 514 pp. 8vo. Chicago, 1886.

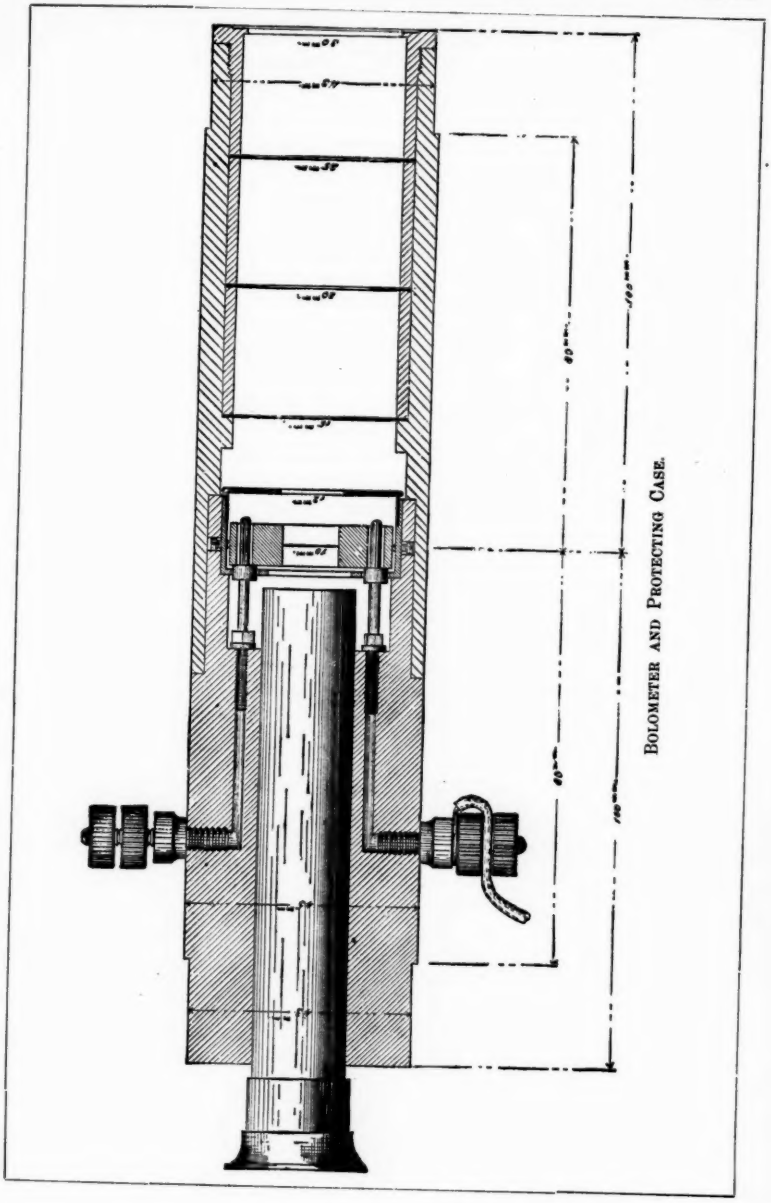
Brachiopoda and Lamellibranchiata of the Raritan Clays and Greensand Marls of New Jersey, by R. P. Whitfield, Geological Survey of New Jersey, and U. S. Geological Survey. G. H. Cook, State Geologist. 277 pp. 4to, with 35 lithographic plates of fossils. 1886.

National Academy of Sciences. Biographical Memoirs. Vol. II. Containing memoirs of Theodore Strong, D. H. Mahan, L. Agassiz. Jeffries Wyman, J. P. Kirtland, S. S. Haldeman, G. K. Warren, W. A. Norton, A. A. Humphreys, J. Lawrence Smith, S. Alexander, J. L. LeConte, J. J. Woodward, Arnold Guyot, J. W. Draper. 382 pp. 8vo. 1886.

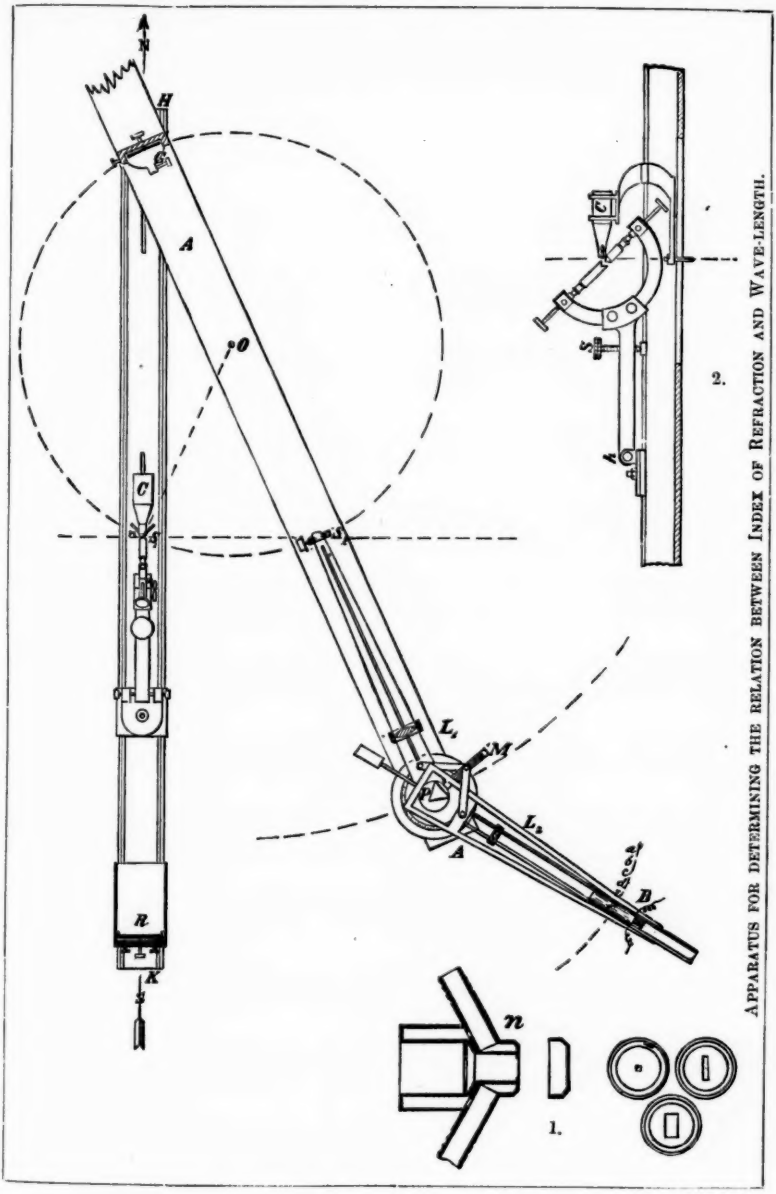
Micrometrical Measures of Gaseous Spectra under high dispersion, by C. Piazzi Smyth, F.R.S.E., Astronomer Royal of Scotland. pp. 415–460, with 31 plates. Edinburgh, 1886 (Trans. Roy. Soc. Edinburgh, xxxii, pt. II).

Solar Heat, Gravitation and Sun Spots, by J. H. Kedzie. 304 pp. 8vo. Chicago, 1886 (S. C. Griggs & Co.)

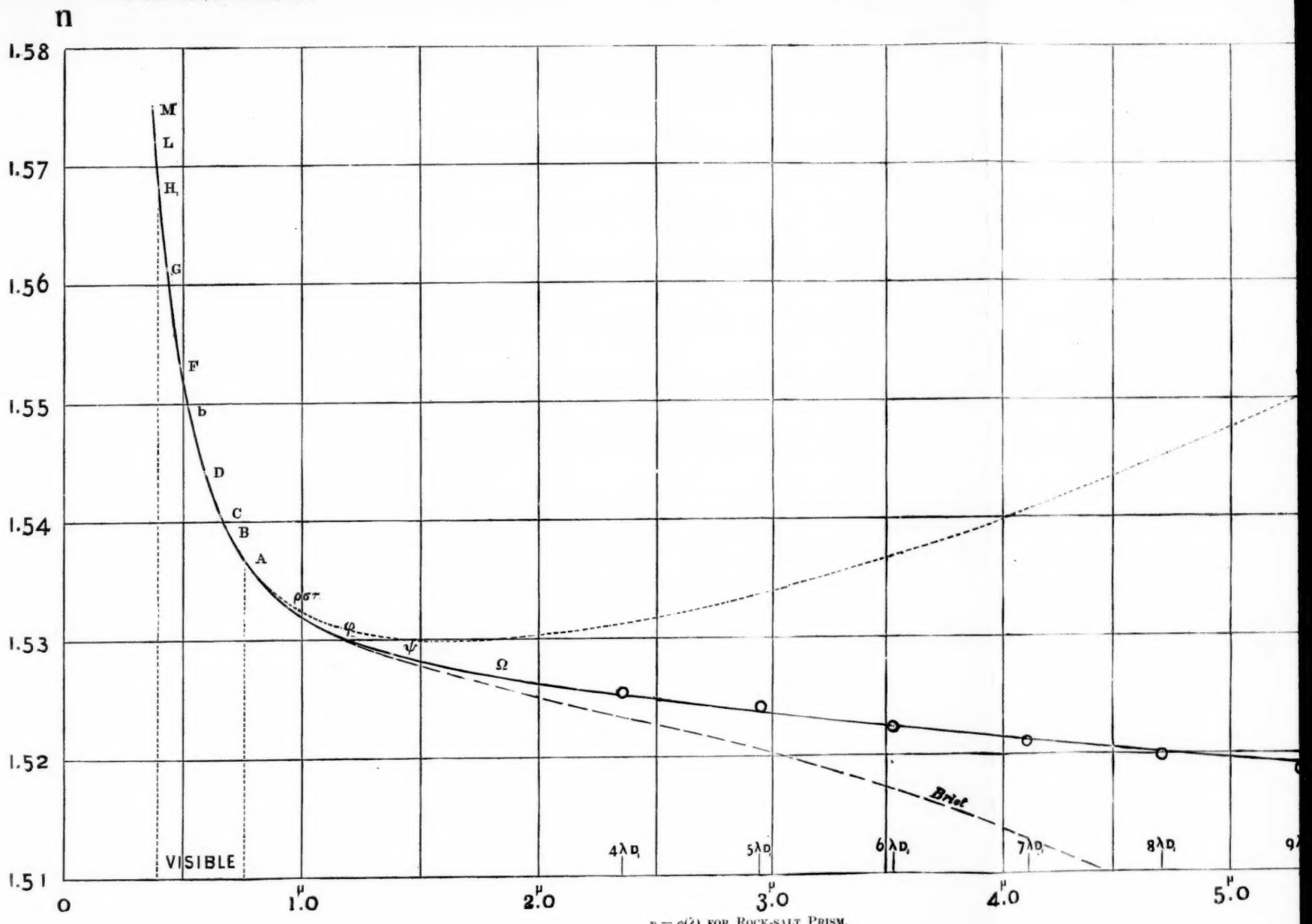

SOLAR ENERGY.
VISIBLE
0°C.
100°C.
78°C.
Normal Spectrum.



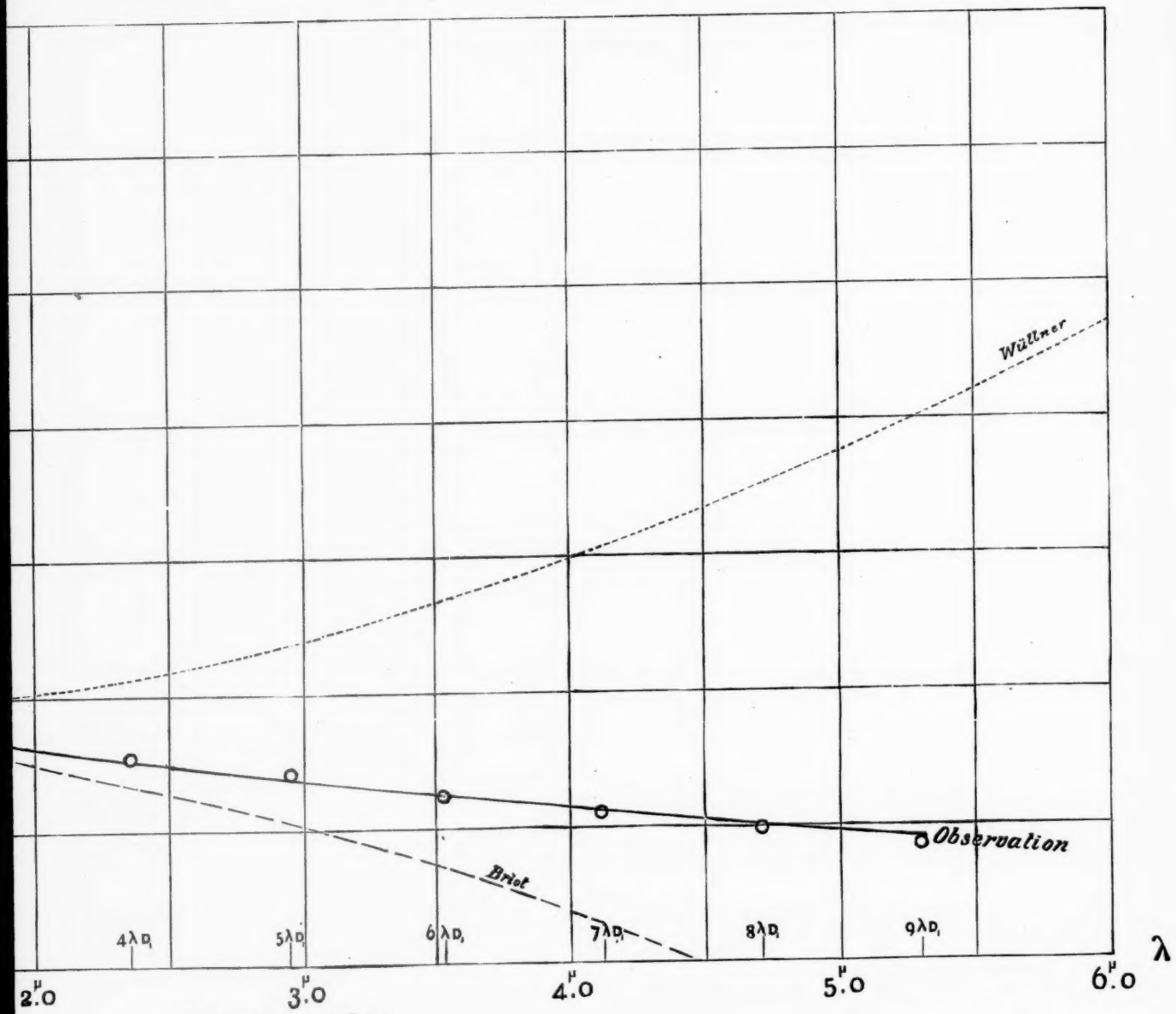
BOLOMETER AND PROTECTING CASE.



APPARATUS FOR DETERMINING THE RELATION BETWEEN INDEX OF REFRACTION AND WAVE-LENGTH.



$n = \varphi(\lambda)$ FOR ROCK-SALT PRISM.



$n = \varphi(\lambda)$ FOR ROCK-SALT PRISM.